Substituted Hydrocarbons and Their Reactions

What You'll Learn

- You will recognize the names and structures of several important organic functional groups.
- You will classify reactions of organic substances as substitution, addition, elimination, oxidation-reduction, or condensation and predict products of these reactions.
- You will relate the structures of synthetic polymers to their properties.

Why It's Important

Whether you are removing a sandwich from plastic wrap, taking an aspirin, or shooting baskets, you're using organic materials made of substituted hydrocarbons. These compounds are in turn made of molecules whose atoms include carbon, hydrogen, and other elements.

CLICK HERE

CHEMISTRY Online

Visit the Chemistry Web site at **science.glencoe.com** to find links about the chemistry of substituted hydrocarbons.

The spooled threads shown in the photo are made from large organic molecules called polymers.

CONTENTS

DISCOVERY LAB

Making Slime

In addition to carbon and hydrogen, most organic substances contain other elements that give the substances unique properties. In this lab, you will work with an organic substance consisting of long carbon chains to which many $-OH$ groups are bonded. How will the properties of this substance change when these groups react to form bonds called crosslinks between the chains?

Materials

4% sodium tetraborate (borax) solution
4% polyvinyl alcohol solution
disposable plastic cup
stirring rod

Safety Precautions

Do not allow solutions or product to contact eyes or exposed skin.

Procedure

1. Pour 20 mL of 4% polyvinyl alcohol solution into a small disposable plastic cup. Note the viscosity of the solution as you stir it.
2. While stirring, add 6 mL of 4% sodium tetraborate solution to the polyvinyl alcohol solution. Continue to stir until there is no further change in the consistency of the product.
3. Use your gloved hand to scoop the material out of the cup. Knead the polymer into a ball.

Analysis

What physical property of the product differs markedly from those of the reactants?

Section 23.1 Functional Groups

Objectives

- **Describe** a functional group and give examples.
- **Name** and **draw** alkyl and aryl halide structures.
- **Discuss** the chemical and physical properties of organic halides.
- **Describe** how substitution reactions form alkyl and aryl halides.

Vocabulary

functional group
halocarbon
alkyl halide
aryl halide
substitution reaction
halogenation

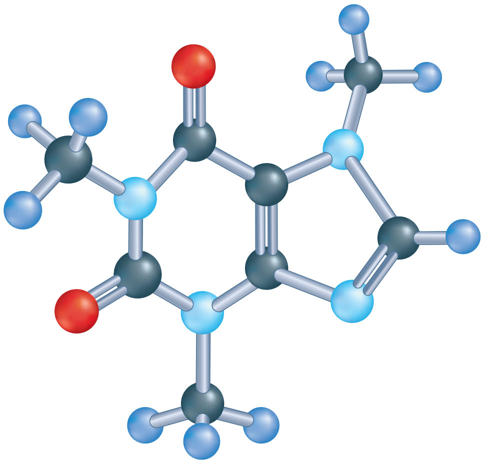
All of the spools shown on the opposite page hold thread manufactured from large organic molecules called polymers. By weaving these polymer threads into fabrics, they can serve many different purposes. Most of the organic molecules used to make these polymers contain atoms of other elements in addition to carbon and hydrogen. The presence of these other elements gives fabric such strength that it can be used to make a bulletproof vest or such resistance to creasing that it never has to be ironed.

Functional Groups

You learned in Chapter 22 that thousands of different hydrocarbons exist because carbon atoms can link together to form straight and branched chains, rings of many sizes, and molecules with single, double, and triple bonds. In hydrocarbons, carbon atoms are linked only to other carbon atoms or hydrogen atoms. But carbon atoms also can form strong covalent bonds with other elements, the most common of which are oxygen, nitrogen, fluorine, chlorine, bromine, iodine, sulfur, and phosphorus.

Atoms of these elements occur in organic substances as parts of functional groups. A **functional group** in an organic molecule is an atom or group of atoms that always reacts in a certain way. The addition of a functional group

to a hydrocarbon structure always produces a substance with physical and chemical properties that differ from those of the parent hydrocarbon. Organic compounds containing several important functional groups are shown in **Table 23-1.** The symbols R and R' represent any carbon chains or rings bonded to the functional group. And * represents a hydrogen atom, carbon chain, or carbon ring.



Caffeine

Figure 23-1

Many organic compounds contain atoms of elements in addition to carbon and hydrogen. For example, caffeine, a compound found in many beverages, contains both oxygen and nitrogen atoms. Refer to **Table C-1** in Appendix C for a key to atom color conventions.

Table 23-1

Organic Compounds and Their Functional Groups

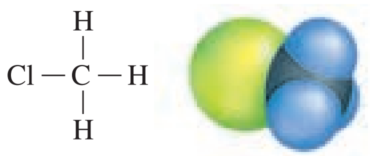
Compound type	General formula	Functional group
Halocarbon	R—X (X = F, Cl, Br, I)	Halogen
Alcohol	R—OH	Hydroxyl
Ether	R—O—R'	Ether
Amine	$R—NH_2$	Amino
Aldehyde	$* - \overset{O}{\overset{\|}{C}} - H$	Carbonyl
Ketone	$R - \overset{O}{\overset{\|}{C}} - R'$	Carbonyl
Carboxylic acid	$* - \overset{O}{\overset{\|}{C}} - OH$	Carboxyl
Ester	$* - \overset{O}{\overset{\|}{C}} - O - R$	Ester
Amide	$* - \overset{O}{\overset{\|}{C}} - \overset{H}{\overset{\mid}{N}} - R$	Amido

Keep in mind that double and triple bonds between two carbon atoms are considered functional groups even though only carbon and hydrogen atoms are involved. By learning the properties associated with a given functional group, you can predict the properties of organic compounds for which you know the structure, even if you have never studied them. Examine the caffeine structure shown in **Figure 23-1** and identify the molecule's functional groups.

Organic Compounds Containing Halogens

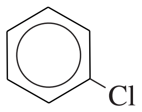
The simplest functional groups can be thought of as substituent groups attached to a hydrocarbon. The elements in group 7A of the periodic table—fluorine, chlorine, bromine, and iodine—are the halogens. Any organic compound that contains a halogen substituent is called a **halocarbon.** If you replace any of the hydrogen atoms in an alkane with a halogen atom, you form an alkyl halide. An **alkyl halide** is an organic compound containing a halogen atom covalently bonded to an aliphatic carbon atom. The first four

halogens—fluorine, chlorine, bromine, and iodine—are found in many organic compounds. For example, chloromethane is the alkyl halide formed when a chlorine atom replaces one of methane's four carbon atoms.



Chloromethane

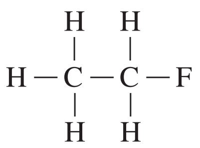
An **aryl halide** is an organic compound containing a halogen atom bonded to a benzene ring or other aromatic group. The structural formula for an aryl halide is created by first drawing the aromatic structure and then replacing its hydrogen atoms with the halogen atoms specified.



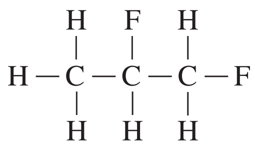
Chlorobenzene

Naming Halocarbons

Organic molecules containing functional groups are given IUPAC names based on their main-chain alkane structures. For the alkyl halides, a prefix indicates which halogen is present. The prefixes are formed by changing the *–ine* at the end of each halogen name to *–o*. Thus, the prefix for fluorine is *fluoro-,* chlorine is *chloro-,* bromine is *bromo-,* and iodine is *iodo-*.

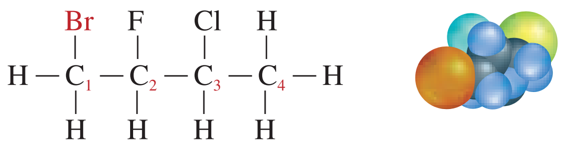


Fluoroethane



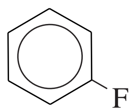
1, 2-Difluoropropane

If more than one kind of halogen atom is present in the same molecule, the atoms are listed alphabetically in the name. The chain also must be numbered in a way that gives the lowest position number to the substituent that comes first in the alphabet. Note how the following alkyl halide is named.

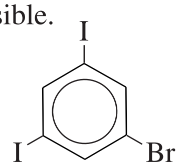


1-Bromo-3-chloro-2-fluorobutane

Note that the benzene ring in an aryl halide is numbered to give each substituent the lowest position number possible.



Fluorobenzene



1-Bromo-3,5-diiodobenzene

Astronomy CONNECTION

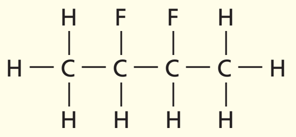
Naphthalene, anthracene, and similar hydrocarbons are termed polycyclic aromatic hydrocarbons (PAHs) because they are composed of multiple aromatic rings. PAHs have been found in meteorites and identified in the material surrounding dying stars. Scientists have mixed PAHs with water ice in a vacuum at –260°C to simulate the conditions found in interstellar clouds. To simulate radiation emitted by nearby stars, they shined ultraviolet light on the mixture. About ten percent of the PAHs were converted to alcohols, ketones, and esters—molecules that can be used to form compounds that are important in biological systems.

For more practice with naming alkyl and aryl halides, go to **Supplemental Practice Problems** in Appendix A.

PRACTICE PROBLEMS

Name the alkyl or aryl halide whose structure is shown.

1.



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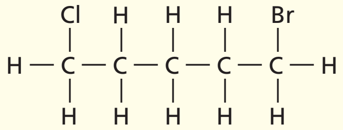

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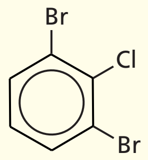


Properties and Uses of Halocarbons

It is easiest to talk about properties of organic compounds containing functional groups by comparing those compounds with alkanes, whose properties were discussed in Chapter 22. **Table 23-2** lists some of the physical properties of certain alkanes and alkyl halides.

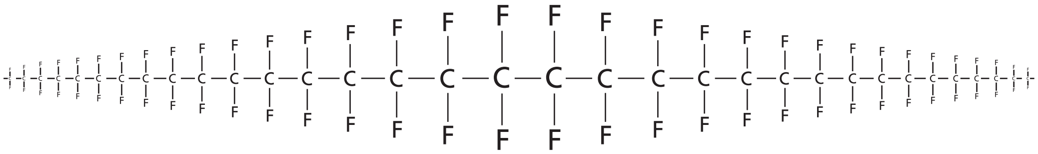
Table 23-2

A Comparison of Alkyl Halides with Their Parent Alkanes

Structure	Name	Boiling point (°C)	Density (g/mL) in liquid state
CH_4	methane	–162	0.423 at –162°C (boiling point)
CH_3Cl	chloromethane	–24	0.911 at 25°C (under pressure)
$CH_3CH_2CH_2CH_2CH_3$	pentane	36	0.626
$CH_3CH_2CH_2CH_2CH_2F$	1-fluoropentane	62.8	0.791
$CH_3CH_2CH_2CH_2CH_2Cl$	1-chloropentane	108 *Increases*	0.882 *Increases*
$CH_3CH_2CH_2CH_2CH_2Br$	1-bromopentane	130	1.218
$CH_3CH_2CH_2CH_2CH_2I$	1-iodopentane	155	1.516

Note that each alkyl chloride has a higher boiling point and a higher density than the alkane with the same number of carbon atoms. Note also that the boiling points and densities increase as the halogen changes from fluorine to chlorine, bromine, and iodine. This trend occurs primarily because the halogens from fluorine to iodine have increasing numbers of electrons that lie farther from the halogen nucleus. These electrons shift position easily and, as a result, the halogen-substituted hydrocarbons have an increasing tendency to form temporary dipoles. Because the dipoles attract each other, the energy needed to separate the molecules also increases. Thus, the boiling points of halogen-substituted alkanes increase as the size of the halogen atom increases.

Alkyl halides are used as solvents and cleaning agents because they readily dissolve nonpolar molecules such as greases. Teflon (polytetrafluoroethene) is a plastic made from gaseous tetrafluoroethylene. Another plastic



Teflon

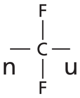
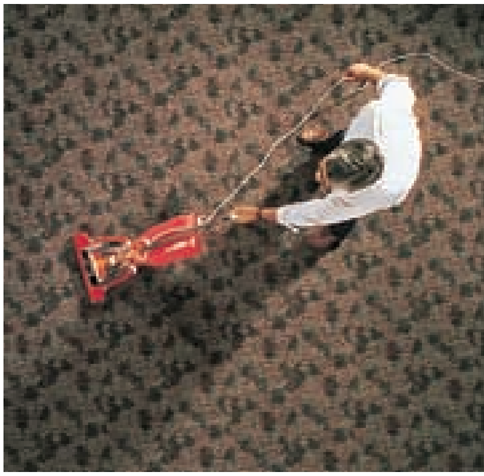
The chain  units extend for hundreds of carbon atoms

Figure 23-2

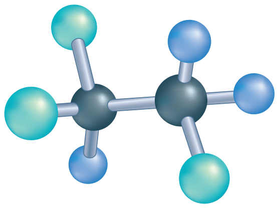
Teflon increases a carpet's resistance to staining and makes it easier to clean.



commonly called *vinyl* is polyvinyl chloride (PVC). It can be manufactured soft or hard, as thin sheets or molded into objects. Organic halides are seldom found in nature, although human thyroid hormones are organic iodides. One example of an organic halide is shown in **Figure 23-2.**

Alkyl halides are widely used as refrigerants. Until the late 1980s, alkyl halides called chlorofluorocarbons (CFCs) were widely used in refrigerators and air-conditioning systems. Because of their potential to damage Earth's ozone layer, CFCs have been replaced by HFCs, hydrofluorocarbons, which contain only hydrogen and fluorine atoms bonded to carbon. One of the more common HFCs is 1,1,2-trifluoroethane, also called R134a.

Halogen atoms bonded to carbon atoms are much more reactive than the hydrogen atoms they replace. For this reason, alkyl halides are often used as starting materials in the chemical industry.

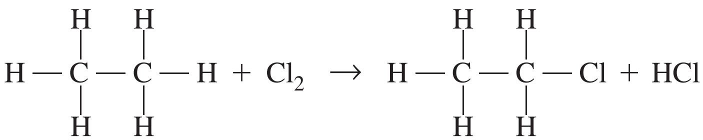


1,1,2–Trifluoroethane
HFC R134a

Substitution Reactions

Where does the immense variety of organic compounds come from? Amazingly enough, the ultimate source of nearly all synthetic organic compounds is petroleum. Petroleum is a fossil fuel that consists almost entirely of hydrocarbons, especially alkanes. How can alkanes be converted into compounds as different as alkyl halides, alcohols, and amines?

One way is to introduce a functional group through substitution. A **substitution reaction** is one in which one atom or a group of atoms in a molecule is replaced by another atom or group of atoms. With alkanes, hydrogen atoms may be replaced by atoms of halogens, typically chlorine or bromine, in a process called **halogenation**. One example of a halogenation reaction is the substitution of a chlorine atom for one of ethane's hydrogen atoms.



Ethane Chloroethane

A substitution reaction

Figure 23-3

Moth balls are used in some closets to protect woolens from damage.1,4-Dichlorobenzene (*p*-dichlorobenzene) is the active ingredient in some brands of moth balls.

Equations for organic reactions are sometimes shown in generic form. The following equation represents the halogenation of alkanes written in generic form.

$$R{-}CH_3 + X_2 \rightarrow R{-}CH_2X + HX$$

In this reaction, X can be fluorine, chlorine, or bromine, but not iodine. Iodine does not react well with alkanes. A common use of a halogented hydrocarbon is shown in **Figure 23-3.**

Once an alkane has been halogenated, the resulting alkyl halide can undergo other kinds of substitution reactions in which the halogen atom is replaced by another atom or group of atoms. For example, reacting an alkyl halide with an aqueous alkali results in the replacement of the halogen atom by an $-OH$ group, forming an alcohol.

$$\underset{\text{Chloroethane}}{CH_3CH_2Cl} + OH^- \rightarrow \underset{\text{Ethanol}}{CH_3CH_2OH} + Cl^-$$

In generic form, the reaction is as follows.

$$\underset{\text{Alkyl halide}}{R{-}X} + OH^- \rightarrow \underset{\text{Alcohol}}{R{-}OH} + X^-$$

Reacting an alkyl halide with ammonia (NH_3) replaces the halogen atom with an amino group ($-NH_2$), forming an alkyl amine, as shown in the following equation.

$$\underset{\text{Alkyl halide}}{R{-}X} + NH_3 \rightarrow \underset{\text{Amine}}{R{-}NH_2} + HX$$

You will learn more about reactions and properties of amines in the next section.

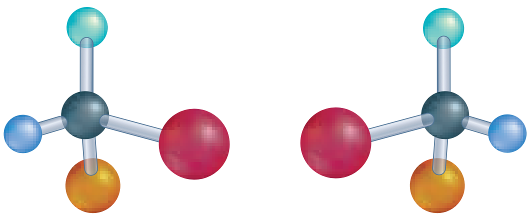
Section 23.1 Assessment

4. Draw structures for the following molecules.
  a. 2-chlorobutane
  b. 1,3-difluorohexane
  c. 1,1,1-trichloroethane
  d. 4-bromo-1-chlorobenzene

5. Name the functional group present in each of the following structures. Name the type of organic compound each substance represents.
  a. $CH_3CH_2CH_2OH$
  b. CH_3CH_2F
  c. $CH_3CH_2NH_2$
  d. $CH_3\overset{\overset{\large O}{\|}}{C}{-}OH$

6. How would you expect the boiling points of propane and 1-chloropropane to compare? Explain your answer.

7. **Thinking Critically** Examine the pair of structures shown below and decide whether it represents a pair of optical isomers. Explain your answer.



8. **Applying Concepts** Place the following substances in order of increasing boiling point. Do not look up boiling points, but use what you learned in this section to suggest the correct order.
2-chloropentane 1-bromohexane butane
2-iodopentane 3-methylpentane

Section 23.2 Alcohols, Ethers, and Amines

Objectives

- **Identify** the functional groups that characterize alcohols, ethers, and amines.
- **Draw** the structures of alcohols, ethers, and amines.
- **Discuss** the properties and uses of alcohols, ethers, and amines.

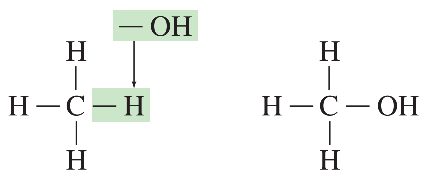
Vocabulary

hydroxyl group
alcohol
denatured alcohol
ether
amine

In Section 23.1, you learned that hydrogen atoms bonded to carbon atoms in hydrocarbons can be replaced by halogen atoms. Many other kinds of atoms or groups of atoms also can bond to carbon in the place of hydrogen atoms. In addition to structural variations, replacement of hydrogen by other elements is a reason that such a wide variety of organic compounds is possible.

Alcohols

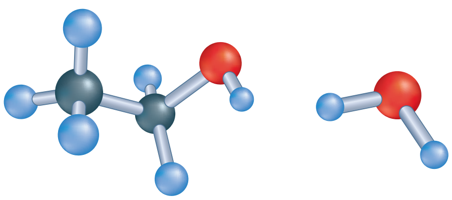
Many organic compounds contain oxygen atoms bonded to carbon atoms. Because an oxygen atom has six valence electrons, it commonly forms two covalent bonds to gain a stable octet. An oxygen atom can form a double bond with a carbon atom, replacing two hydrogen atoms, or it can form one single bond with a carbon atom and another single bond with another atom, such as hydrogen. An oxygen-hydrogen group covalently bonded to a carbon atom is called a **hydroxyl group** (—OH). An organic compound in which a hydroxyl group replaces a hydrogen atom of a hydrocarbon is called an **alcohol**. The general formula for an alcohol is ROH. The following diagram illustrates the relationship of the simplest alkane, methane, to the simplest alcohol, methanol.



Methane (CH_4) — Alkane
Methanol (CH_3OH) — Alcohol

Ethanol, a two-carbon alcohol, and carbon dioxide are produced by yeasts when they ferment sugars, such as those in grapes and bread dough. Ethanol is found in alcoholic beverages and medicinal products. Because it is an effective antiseptic, ethanol may be used to swab skin before an injection is given, as shown in **Figure 23-4.** It also is a gasoline additive and an important starting material for the synthesis of more complex organic compounds.

Models of an ethanol molecule and a water molecule are shown in the following diagram.



Ethanol — Water

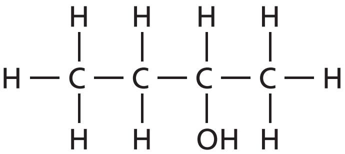
As you compare the models, you can see that the covalent bonds from oxygen are at approximately the same angle as they are in water. Therefore, the hydroxyl groups of alcohol molecules are moderately polar, as with water, and are able to form hydrogen bonds with the hydroxyl groups of other alcohol molecules. As a result, alcohols have much higher boiling points than

Figure 23-4

Ethanol is an effective antiseptic used to sterilize skin before an injection. It also is found in antiseptic hand cleaners.

hydrocarbons of similar shape and size. Also, because of polarity and hydrogen bonding, ethanol is completely miscible with water. In fact, once they are mixed, it is difficult to separate water and ethanol completely. Distillation is used to remove ethanol from water, but even after that process is complete, about 5% water remains in the ethanol-water mixture.

On the shelves of drugstores you can find bottles of ethanol labeled denatured alcohol. **Denatured alcohol** is ethanol to which small amounts of noxious materials such as aviation gasoline or other organic solvents have been added. Ethanol is denatured in order to make it unfit to drink. Because of their polar hydroxyl groups, alcohols make good solvents for other polar organic substances. For example, methanol, the smallest alcohol, is a common industrial solvent found in some paint strippers, and 2-butanol is found in some stains and varnishes, as shown in **Figure 23-5.** Perform the **CHEMLAB** at the end of this chapter to learn about some other properties of small-chain alcohols.

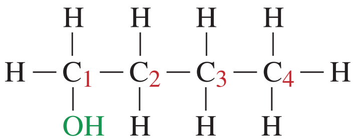


2-Butanol

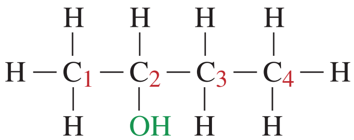
Figure 23-5

Because it evaporates more slowly than smaller alcohol molecules, 2-butanol is used as a solvent in some stains and varnishes. Draw the structures of two other alcohols that have the same molecular formula as 2-butanol, $C_4H_{10}O$.

Note that the names of alcohols are based on alkane names, like the names of alkyl halides. For example, CH_4 is methane and CH_3OH is methanol; CH_3CH_3 is ethane and CH_3CH_2OH is ethanol. When naming a simple alcohol based on an alkane carbon chain, the IUPAC rules call for naming the parent carbon chain or ring first and then changing the *–e* at the end of the name to *–ol* to indicate the presence of a hydroxyl group. In alcohols of three or more carbon atoms, the hydroxyl group can be at two or more positions. To indicate the position, a prefix consisting of a number followed by a dash is added. For example, examine the names and structures of two isomers of butanol shown below. Explain why the names *3-butanol* and *4-butanol* cannot represent real substances.

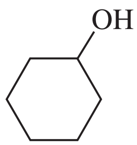


1-Butanol
bp = 99.5°C



2-Butanol
bp = 115°C

Now look at the following structural formula. What is the name of this compound?

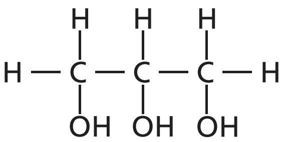


You are correct if you said *cyclohexanol.* The compound's ring structure contains six carbons with only single bonds so you know that the parent hydrocarbon is cyclohexane. Because an −OH group is bonded to a carbon, it is an alcohol and the name will end in *–ol.* No number is necessary because all carbons in the ring are equivalent. Cyclohexanol is a poisonous compound used as a solvent for certain plastics and in the manufacture of insecticides.

A carbon chain also can have more than one hydroxyl group. To name these compounds, prefixes such as *di-, tri-,* and *tetra-* are used before the *–ol* to indicate the number of hydroxyl groups present. The full alkane name, including *–ane,* is used before the prefix as in the following example. 1,2,3-propanetriol, commonly called glycerol, is another alcohol containing more than one hydroxyl group, **Figure 23-6.**

Figure 23-6

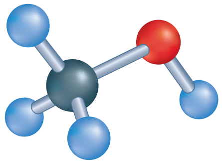
Glycerol is a liquid often used in automobile antifreeze and airplane deicing fluid.



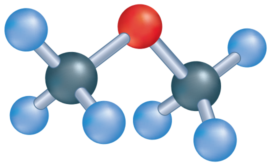
1,2,3-Propanetriol
(glycerol)

Ethers

Ethers are another group of organic compounds in which oxygen is bonded to carbon. An **ether** is an organic compound containing an oxygen atom bonded to two carbon atoms. Ethers have the general formula ROR'. The simplest ether is one in which oxygen is bonded to two methyl groups. Note the relationship between methanol and methyl ether in the following diagram.



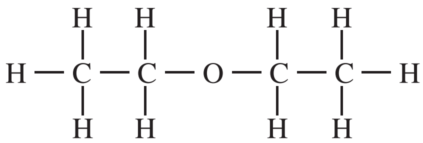
Methanol
bp = 65°C



Methyl ether
bp = –25°C

Because ethers have no hydrogen atoms bonded to the oxygen atom, their molecules cannot form hydrogen bonds with each other. Therefore, ethers generally are more volatile and have much lower boiling points than alcohols of similar size and mass. Ethers are much less soluble in water than alcohols because they have no hydrogen to donate to a hydrogen bond. However, the oxygen atom can act as a receptor for the hydrogen atoms of water molecules.

The term *ether* was first used in chemistry as a name for ethyl ether, the volatile, highly flammable substance that was commonly used as an anesthetic in surgery from 1842 into the twentieth century, **Figure 23-7.** As time passed, the term *ether* was applied to other organic substances having two hydrocarbon chains attached to the same oxygen atom.

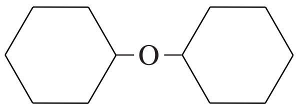


Ethyl ether

Name ethers that have two identical alkyl chains bonded to oxygen by first naming the alkyl group and then adding the word *ether.* Here are the names and structures of two of these symmetrical ethers.

$CH_3CH_2CH_2-O-CH_2CH_2CH_3$

Propyl ether



Cyclohexyl ether

If the two alkyl groups are different, they are listed in alphabetical order and then followed by the word ether. Such ethers are asymmetrical, or uneven, in appearance.

$CH_3CH_2-O-CH_2CH_2CH_2CH_3$

Butylethyl ether

$CH_3CH_2-O-CH_3$

Ethylmethyl ether

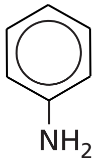
Amines

Another class of organic compounds contains nitrogen. **Amines** contain nitrogen atoms bonded to carbon atoms in aliphatic chains or aromatic rings and have the general formula RNH_2.

Figure 23-7

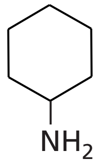
An apparatus similar to the one held by the man on the left was used to administer ether to patients in the 1840s. Dr. Crawford W. Long of Georgia discovered the anesthetic properties of ethyl ether in 1842.

a



Aniline

b



Cyclohexylamine

CH_3CH_2
|
NH_2

Ethylamine

Figure 23-8

a Aniline is an important industrial substance, especially in the production of dyes with deep shades of color. **b** Cyclohexylamine and ethylamine are important in the manufacture of pesticides, plastics, pharmaceuticals, and the rubber used to make the tires for this race car.

When naming amines, the $-NH_2$ (amino) group is indicated by the suffix *-amine*. When necessary, the position of the amino group is designated by a number. If more than one amino group is present, the prefixes *di-*, *tri-*, *tetra-*, and so on are used to indicate the number of groups.

$$\begin{array}{ccc} CH_2 & CH_2 & CH_2 \\ | & & | \\ NH_2 & & NH_2 \end{array}$$

1,3-Propanediamine

$$\begin{array}{cccc} NH_2 & & & NH_2 \\ | & & & | \\ CH & CH_2 & CH_2 & CH \\ | & & & | \\ NH_2 & & & NH_2 \end{array}$$

1,1,4,4-Butanetetraamine

Examples of amines used in industry are shown in **Figure 23-8.** All volatile amines have odors that humans find offensive, and amines are responsible for many of the odors characteristic of dead, decaying organisms.

Section 23.2 Assessment

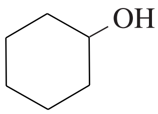
9. Draw structures for the following alcohols:
  a. 1-propanol
  b. 2-propanol
  c. 2-methyl-2-butanol
  d. 1,3-cyclopentanediol

10. Draw structures for the following molecules:
  a. propyl ether
  b. ethylpropyl ether
  c. 1,2-propanediamine
  d. cyclobutylamine

11. Identify the functional group present in each of the following structures. Name the substance represented by each structure.

a.
$$\begin{array}{c} NH_2 \\ | \\ CH_3CHCH_3 \end{array}$$

b.



c. $CH_3-O-CH_2CH_2CH_3$

12. **Thinking Critically** Which of the following compounds would you expect to be more soluble in water? Explain your reasoning.

CH_3-O-CH_3

$$\begin{array}{c} OH \\ | \\ CH_3CH_2 \end{array}$$

13. **Applying Concepts** Alcohols and amines are used as starting materials in reactions that produce useful substances such as pharmaceuticals, plastics, and synthetic fibers, as well as other industrial chemicals. What properties of these compounds make them more useful than hydrocarbons for this purpose?

Section 23.3 Carbonyl Compounds

Objectives

- **Draw** and **identify** the structures of carbonyl compounds including aldehydes, ketones, carboxylic acids, esters, and amides.
- **Discuss** the properties and uses of compounds containing the carbonyl group.

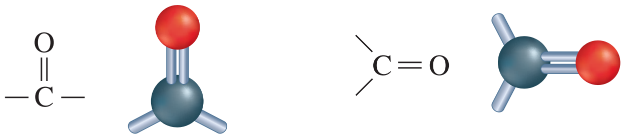
Vocabulary

carbonyl group
aldehyde
ketone
carboxylic acid
carboxyl group
ester
amide
condensation reaction

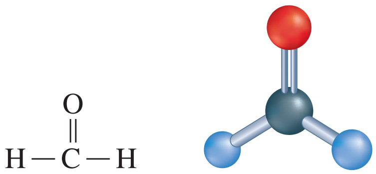
You have now learned that in the organic compounds known as alcohols and ethers, oxygen is bonded to two different atoms. In other kinds of organic compounds, an oxygen atom is double-bonded to a carbon atom.

Organic Compounds Containing the Carbonyl Group

The arrangement in which an oxygen atom is double-bonded to a carbon atom is called a **carbonyl group**. This group, which can be represented as shown below, is the functional group in organic compounds known as aldehydes and ketones.



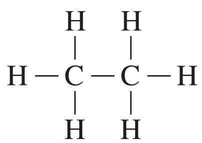
Aldehydes An **aldehyde** is an organic compound in which a carbonyl group located at the end of a carbon chain is bonded to a carbon atom on one side and a hydrogen atom on the other. Aldehydes have the general formula *CHO, where * represents an alkyl group or a hydrogen atom.



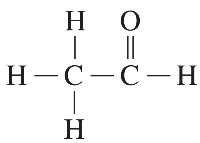
Methanal (formaldehyde)

Aldehydes are formally named by changing the final *–e* of the name of the alkane with the same number of carbon atoms to the suffix *–al*. Thus, the formal name of the compound represented above is methanal, based on the one-carbon alkane methane. Methanal is commonly called formaldehyde. A water solution of formaldehyde was used in the past to preserve biological specimens. However, formaldehyde's use has been restricted in recent years because evidence shows it may cause cancer. Industrially, large quantities of formaldehyde are reacted with urea to manufacture a type of grease-resistant, hard plastic used to make buttons, appliance and automotive parts, and electrical outlets, as well as the glue that holds the layers of plywood together.

Note the relationship between the structures and names of ethane and ethanal in the following diagram.



Ethane



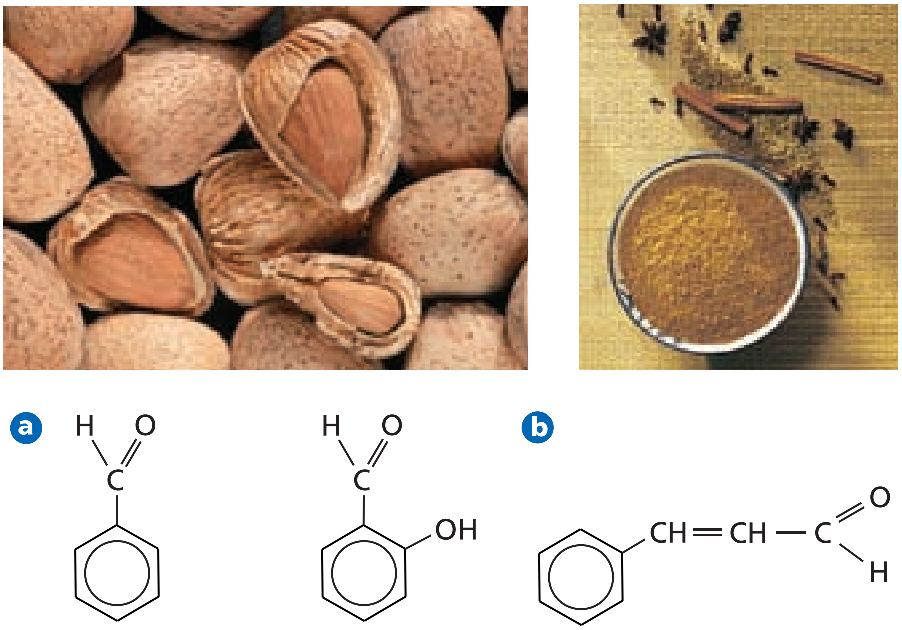
Ethanal
(acetaldehyde)

Ethanal also has the common name *acetaldehyde.* Scientists often use the common names of organic compounds because they are so familiar to chemists. Because the carbonyl group in an aldehyde always occurs at the end of a carbon chain, no numbers are used in the name unless branches or additional functional groups are present.

Many aldehydes have characteristic odors and flavors. **Figure 23-9** shows examples of naturally occurring aldehydes.

Figure 23-9

a Benzaldehyde and salicylaldehyde are two components of the flavor of almonds. **b** The aroma and flavor of cinnamon are produced largely by cinnamaldehyde. Cinnamon is the ground bark of a tropical tree.



Benzaldehyde   Salicylaldehyde   Cinnamaldehyde

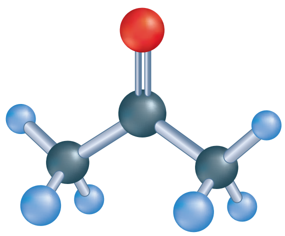
An aldehyde molecule contains a polar, reactive structure. However, like ethers, aldehyde molecules cannot form hydrogen bonds among themselves because the molecules have no hydrogen atoms bonded to an oxygen atom. Therefore, aldehydes have lower boiling points than alcohols with the same number of carbon atoms. Water molecules can form hydrogen bonds with the oxygen atom of aldehydes, so aldehydes are more soluble in water than alkanes but not as soluble as alcohols or amines.

Ketones A carbonyl group also can be located within a carbon chain rather than at the end. A **ketone** is an organic compound in which the carbon of the carbonyl group is bonded to two other carbon atoms. Ketones have the general formula

$$\mathrm{R-\overset{\overset{\displaystyle O}{\|}}{C}-R'} \qquad \begin{array}{ccccccc} & & | & & \overset{\displaystyle O}{\|} & & | & \\ & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - \\ & & | & & & & | & \end{array}$$

The carbon atoms on either side of the carbonyl group are bonded to other atoms. The simplest ketone has only hydrogen atoms bonded to the side carbons, as shown in the following diagram. The common name of this ketone is acetone.

$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{O} & & \mathrm{H} & & \\ & & | & & \| & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & & & | & & \\ & & \mathrm{H} & & & & \mathrm{H} & & \end{array}$$



2-Propanone (acetone)

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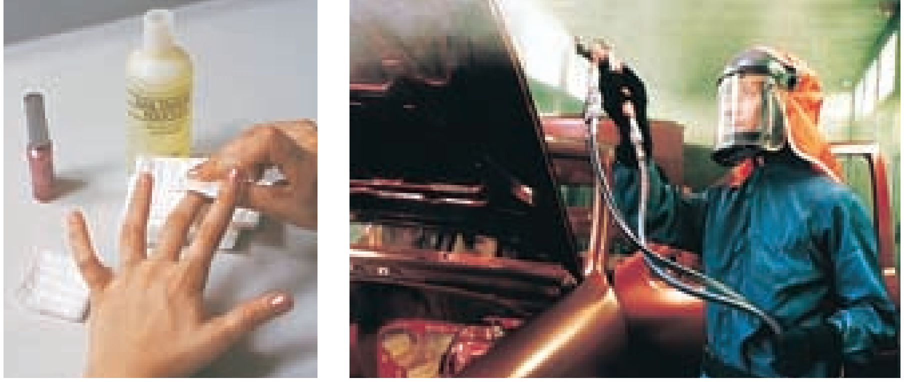
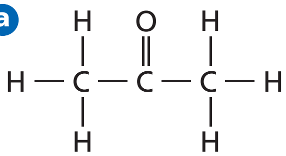


Figure 23-10

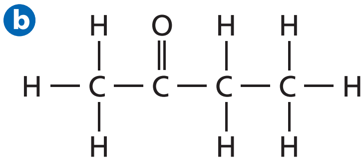
a The solvent 2-propanone (acetone) is used in fingernail polish; it can dissolve and remove the polish as well. **b** Although the solvent 2-butanone is not familiar to most people, it is a popular solvent in industries that put coatings on other materials.

a



2-Propanone
(acetone)

b



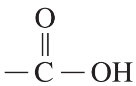
2-Butanone
(methyethyl ketone)

Ketones are formally named by changing the *-e* at the end of the alkane name to *-one,* and including a number before the name to indicate the position of the ketone group. In the previous example, the alkane name propane is changed to propan*one.* The carbonyl group can be located only in the center, but the prefix *2-* is usually added to the name for clarity. **Figure 23-10** shows representative ketones and their uses.

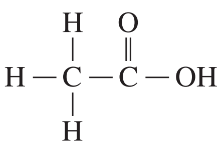
Ketones and aldehydes share many chemical and physical properties because their structures are so similar. Ketones are polar molecules and are less reactive than aldehydes. For this reason, ketones are popular solvents for other moderately polar substances, including waxes, plastics, paints, lacquers, varnishes, and glues. Like aldehydes, ketone molecules cannot form hydrogen bonds with each other but can form hydrogen bonds with water molecules. Therefore, ketones are somewhat soluble in water. Acetone is completely miscible with water.

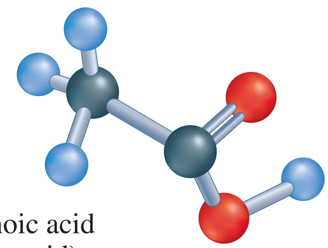
Carboxylic Acids

A **carboxylic acid** is an organic compound that has a carboxyl group. A **carboxyl group** consists of a carbonyl group bonded to a hydroxyl group. Thus, carboxylic acids have the general formula



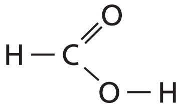
The following diagram shows the structure of a carboxylic acid familiar to you—acetic acid, the acid found in vinegar.





Ethanoic acid
(acetic acid)

Although many carboxylic acids have common names, the formal name is formed by changing the *-ane* of the parent alkane to *-anoic acid*. Thus, the formal name of acetic acid is ethanoic acid.



Formic acid

Figure 23-11

Formic acid is the simplest carboxylic acid. Stinging ants produce formic acid as a defense mechanism.

A carboxyl group is usually represented in condensed form by writing $-COOH$. For example, ethanoic acid can be written as CH_3COOH. The simplest carboxylic acid consists of a carboxyl group bonded to a single hydrogen atom, HCOOH. Its formal name is methanoic acid, but it is more commonly known as formic acid. See **Figure 23-11.**

Carboxylic acids are polar and reactive. Those that dissolve in water ionize weakly to produce hydronium ions and the anion of the acid in equilibrium with water and the un-ionized acid. The ionization of ethanoic acid is an example.

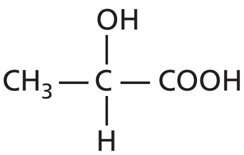
$$\underset{\substack{\text{Ethanoic acid}\\ \text{(acetic acid)}}}{CH_3COOH(aq)} + H_2O(l) \rightleftharpoons \underset{\substack{\text{Ethanoate ion}\\ \text{(acetate ion)}}}{CH_3COO^-(aq)} + H_3O^+(aq)$$

Carboxylic acids can ionize in water solution because the two oxygen atoms are highly electronegative and attract electrons away from the hydrogen atom in the $-OH$ group. As a result, the hydrogen proton can transfer to another atom that has a pair of electrons not involved in bonding, such as the oxygen atom of a water molecule. Because they ionize in water, soluble carboxylic acids turn blue litmus paper red and have a sour taste.

Some important carboxylic acids, such as oxalic acid and adipic acid, have two or more carboxyl groups. An acid with two carboxyl groups is called a dicarboxylic acid. Others have additional functional groups such as hydroxyl groups, as shown in **Figure 23-12.** Typically, these acids are more soluble in water and often more acidic than acids with only a carboxyl group.

Figure 23-12

Lactic acid produces the tangy taste of buttermilk. It also accumulates in the muscles during heavy exercise.

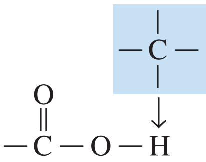


Lactic acid

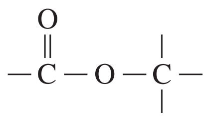
Organic Compounds Derived From Carboxylic Acids

Several classes of organic compounds have structures in which the hydrogen or the hydroxyl group of a carboxylic acid is replaced by a different atom or group of atoms. The two most common classes are esters and amides.

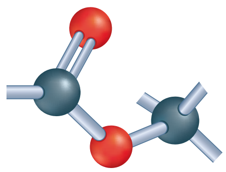
Esters An **ester** is any organic compound with a carboxyl group in which the hydrogen of the hydroxyl group has been replaced by an alkyl group, producing the following arrangement



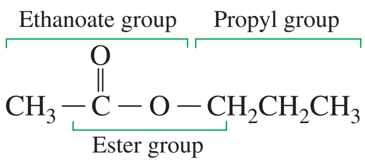
Carboxyl group



Ester group



The name of an ester is formed by writing the name of the alkyl group followed by the name of the acid with the *–ic acid* ending replaced by *-ate,* as illustrated by the example shown below. Note how the name *propyl ethanoate*



Propyl ethanoate
(propyl acetate)

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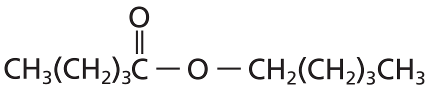
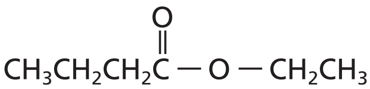
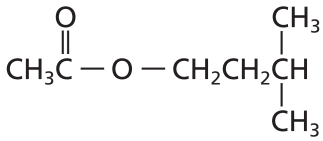


Pentyl pentanoate



Ethyl butanoate



3-Methylbutyl acetate

Figure 23-13

Esters are responsible for the flavors and aromas of many fruits. Pentyl pentanoate smells like ripe apples. Ethyl butanoate has the aroma of pineapples, and 3-methylbutyl acetate smells like bananas although it imparts a pear flavor to foods. Most natural aromas and flavors are mixtures of esters, aldehydes, and alcohols.

results from the structural formula. The name shown in parentheses is based on the name *acetic acid,* the common name for ethanoic acid.

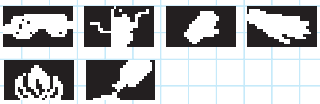
Esters are polar molecules and many are volatile and sweet-smelling. Many kinds of esters are found in the natural fragrances and flavors of flowers and fruits. Natural flavors such as apple or banana result from mixtures of many different organic molecules, including esters. See **Figure 23-13.** But some of these flavors can be imitated by a single ester structure. Consequently, esters are manufactured for use as flavors in many foods and beverages and as fragrances in candles, perfumes, and other scented items. You will prepare an ester in the following **miniLAB.**

miniLAB

Making an Ester

Observing and Inferring Flowers and fruits have pleasant odors partly because they contain substances called esters. Companies make blends of synthetic esters to mimic the flavors and fragrances of esters found in nature. In this experiment, you will make an ester that has a familiar smell.

Materials salicylic acid, methanol, distilled water, 10-mL graduated cylinder, Beral pipette, 250-mL beaker, concentrated sulfuric acid, top or bottom of a petri dish, cotton ball, small test tube, balance, weighing paper, hot plate, test-tube holder

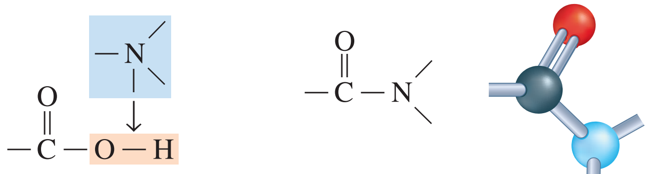
Procedure 

1. Prepare a hot-water bath by pouring 150 mL of tap water into a 250-mL beaker. Place the beaker on a hot plate set at medium.
2. Place 1.5 g of salicylic acid in a small test tube and add 3 mL of distilled water. Then add 3 mL of methanol and 3 drops of concentrated sulfuric acid to the test tube. **CAUTION:** *Sulfuric acid is corrosive. Handle with care.*
3. When the water is hot but not boiling, place the test tube in the bath for 5 minutes.
4. Place the cotton ball in the petri dish half. Pour the contents of the test tube onto the cotton ball. Record your observation of the odor of the product.

Analysis

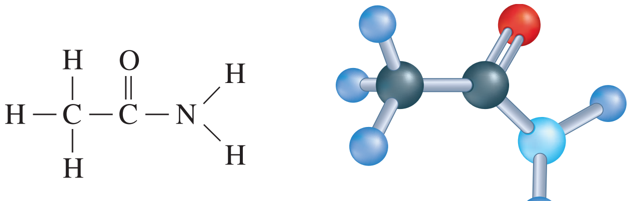
1. The ester you produced has the common name oil of wintergreen. Write a chemical equation using names and structural formulas for the reaction that produced the ester.
2. What are the advantages and disadvantages of using synthetic esters in consumer products as compared to using natural esters?
3. Name some products that you think could contain the ester you made in this experiment.

Amides An **amide** is an organic compound in which the $-OH$ group of a carboxylic acid is replaced by a nitrogen atom bonded to other atoms. The general structure of an amide is shown below.



Carboxyl group   Amide group

Amides are named by writing the name of the alkane with the same number of carbon atoms, and then replacing the final *–e* with *–amide*. Thus, the amide shown below is called ethanamide, but it also may be named acetamide from the common name, acetic acid.



Ethanamide (acetamide)

The amide functional group is found repeated many times in natural proteins and some synthetic materials. For example, you may have used a nonaspirin pain reliever containing acetaminophen. In the acetaminophen structure shown below, you can see that the amide ($-NH-$) group connects a carbonyl group and an aromatic group.

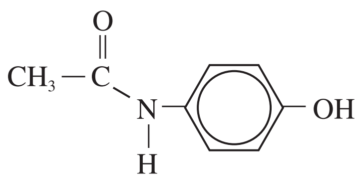
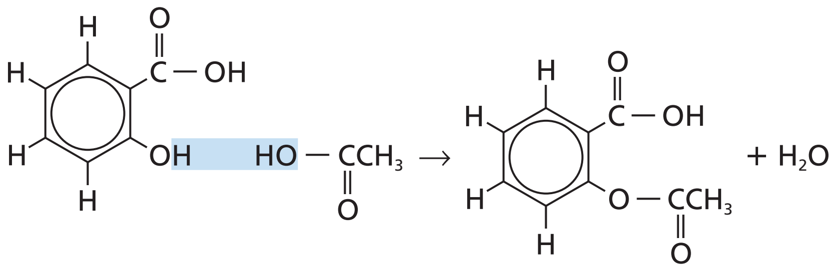


Figure 23-14

To synthesize aspirin, two organic molecules are combined in a condensation reaction to form a larger molecule.

Condensation Reactions

Many laboratory syntheses and industrial processes involve the reaction of two organic reactants to form a larger organic product, such as the aspirin shown in **Figure 23-14.** This type of reaction is known as a condensation reaction.



Salicylic acid   Acetic acid   Acetylsalicylic acid (aspirin)   Water

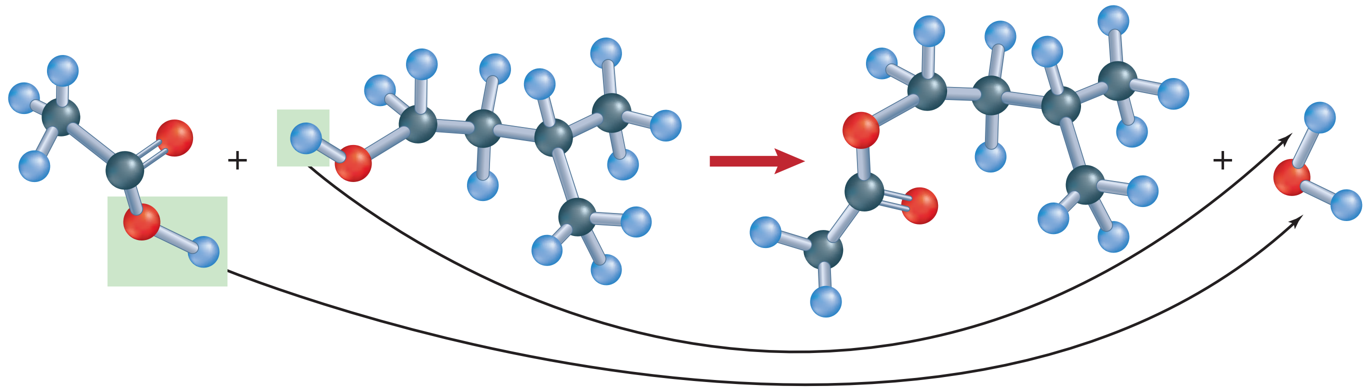


Figure 23-15

When ethanoic acid and 3-methylbutanol undergo a condensation reaction, the ester 3-methylbutyl ethanoate is formed. The water molecule eliminated is made up of the −OH group from the acid and the H− from the alcohol.

In a **condensation reaction,** two smaller organic molecules combine to form a more complex molecule, accompanied by the loss of a small molecule such as water. Typically, the molecule lost is formed from one particle from each of the reactant molecules. In essence, a condensation reaction is an elimination reaction in which a bond is formed between two atoms not previously bonded to each other.

The most common condensation reactions involve the combining of carboxylic acids with other organic molecules. A common way to synthesize an ester is by a condensation reaction between a carboxylic acid and an alcohol. Such a reaction can be represented by the general equation

$$RCOOH + R'OH \rightarrow RCOOR' + H_2O$$

For example, the reaction represented by the ball-and-stick models in **Figure 23-15** produces an ester that is a part of artificial banana flavoring.

Section 23.3 Assessment

14. Draw the structure for a carbonyl group.

15. Classify each of the following structures as one of the types of organic substances you have studied in this section.

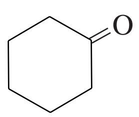
a. $CH_3CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C}H$

b. $CH_3CH_2\overset{\overset{\displaystyle O}{\|}}{C}CH_3$

c. $CH_3CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C}-OH$

d. $CH_3CH_2-O-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3$

e. $CH_3CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C}-NH_2$

f. 

16. What are the products of a condensation reaction between a carboxylic acid and an alcohol?

17. What features of the substances discussed in this section make many of them useful solvents? Explain how these features affect the properties of the molecules.

18. **Thinking Critically** Suggest a reason for the observation that water-soluble organic compounds with carboxyl groups exhibit acidic properties in solutions, whereas similar compounds with aldehyde structures do not.

19. **Formulating Models** You learned that the molecular formulas for alkanes follow the pattern C_nH_{2n+2}. Derive a general formula to represent an aldehyde, a ketone, and a carboxylic acid. Could you examine a molecular formula for one of these three types of compounds and determine which type the formula represents? Explain.

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Section 23.4

Other Reactions of Organic Compounds

Objectives

- **Classify** an organic reaction into one of five categories: substitution, addition, elimination, oxidation-reduction, or condensation.
- **Use** structural formulas to write equations for reactions of organic compounds.
- **Predict** the products of common types of organic reactions.

Vocabulary

elimination reaction
dehydrogenation reaction
dehydration reaction
addition reaction
hydration reaction
hydrogenation reaction

Organic chemists have discovered thousands of reactions by which organic compounds can be changed into different organic compounds. By using combinations of these reactions, chemical industries convert simple molecules from petroleum and natural gas into the large, complex organic molecules found in many useful products—from lifesaving drugs to the plastic case of a telephone. See **Figure 23-16.**

Reactions of Organic Substances

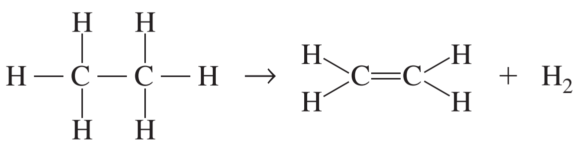
It is important to understand why organic reactions differ from inorganic reactions. For any chemical reaction to occur, existing bonds must be broken and new bonds formed. As you have learned, the bonds in organic substances are covalent. Because covalent bonds are fairly strong, this rearrangement of bonds causes many reactions of organic compounds to be slow and require a continuous input of energy to keep molecules moving rapidly and colliding. Sometimes catalysts must be used to speed up organic reactions that could otherwise take days, months, or even longer to yield usable amounts of product. Often, bonds can break and re-form in several different positions. Consequently, nearly all organic reactions result in a mixture of products. The unwanted products must then be separated from the expected product, a process that often requires much time and manipulation.

Classifying Organic Reactions

You've already learned about substitution and condensation reactions in Sections 23.1 and 23.3. Two other important types of organic reactions are elimination and addition.

Elimination reactions One way to change an alkane into a chemically reactive substance is to form a second covalent bond between two carbon atoms, producing an alkene. The main industrial source of alkenes is the cracking of petroleum. The process of cracking, shown in **Figure 23-17,** breaks large alkanes into smaller alkanes, alkenes, and aromatic compounds. Why do you suppose the term *cracking* was applied to this process?

The formation of alkenes from alkanes is an **elimination reaction,** a reaction in which a combination of atoms is removed from two adjacent carbon atoms forming an additional bond between the carbon atoms. The atoms that are eliminated usually form stable molecules, such as H_2O, HCl, or H_2. Ethene, an important starting material in the chemical industry, is produced by the elimination of two hydrogen atoms from ethane. A reaction that eliminates two hydrogen atoms is called a **dehydrogenation reaction.** Note that the two hydrogen atoms form a molecule of hydrogen gas.



Ethane Ethene

An elimination reaction (dehydrogenation)

Figure 23-16

Through organic chemical reactions, the aliphatic and aromatic substances in petroleum are changed into compounds used to manufacture many important products, some of which are shown here.

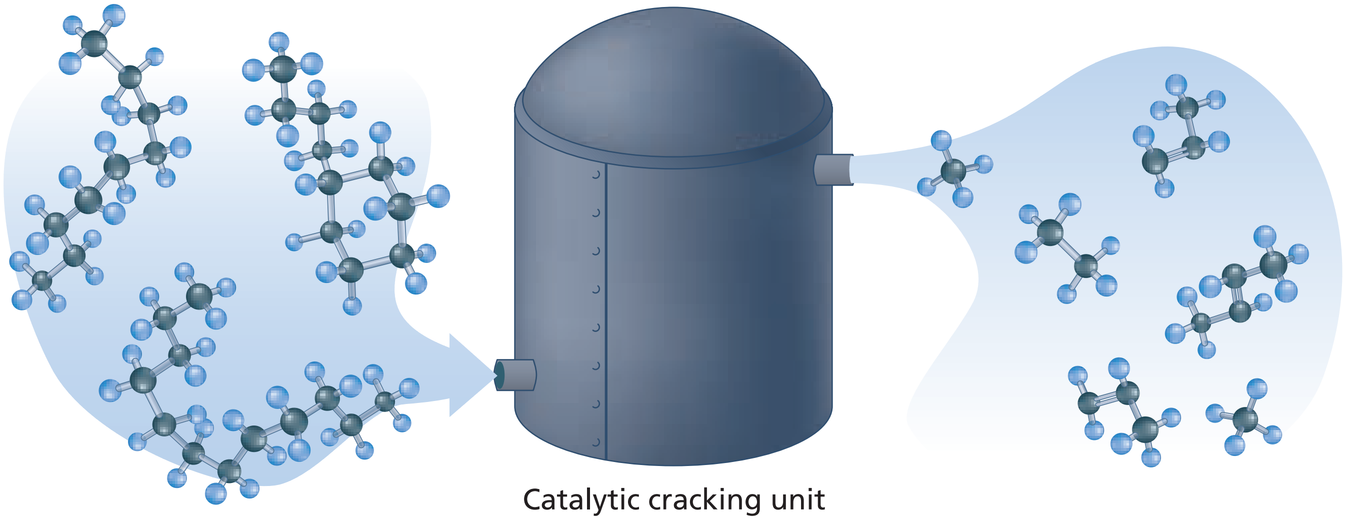


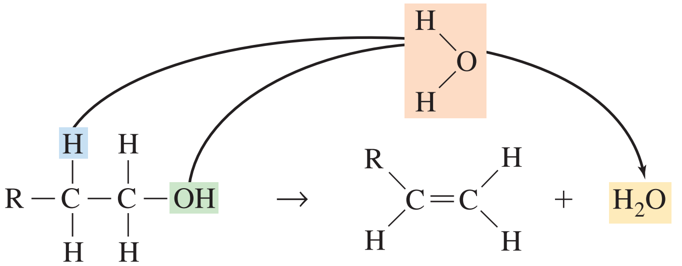
Figure 23-17

The process of catalytic cracking breaks long-chain alkanes into smaller alkanes and alkenes that are more valuable to industry.

Alkyl halides can undergo elimination reactions to produce an alkene and a hydrogen halide, as shown here.

$$\underset{\text{Alkyl halide}}{R{-}CH_2{-}CH_2{-}X} \longrightarrow \underset{\text{Alkene}}{R{-}CH{=}CH_2} + \underset{\text{Hydrogen halide}}{HX}$$

Likewise, alcohols also can undergo elimination reactions by losing a hydrogen atom and a hydroxyl group to form water. An elimination reaction in which the atoms removed form water is called a **dehydration reaction.** In the following dehydration reaction, the alcohol is broken down into an alkene and water.



Alcohol Alkene Water

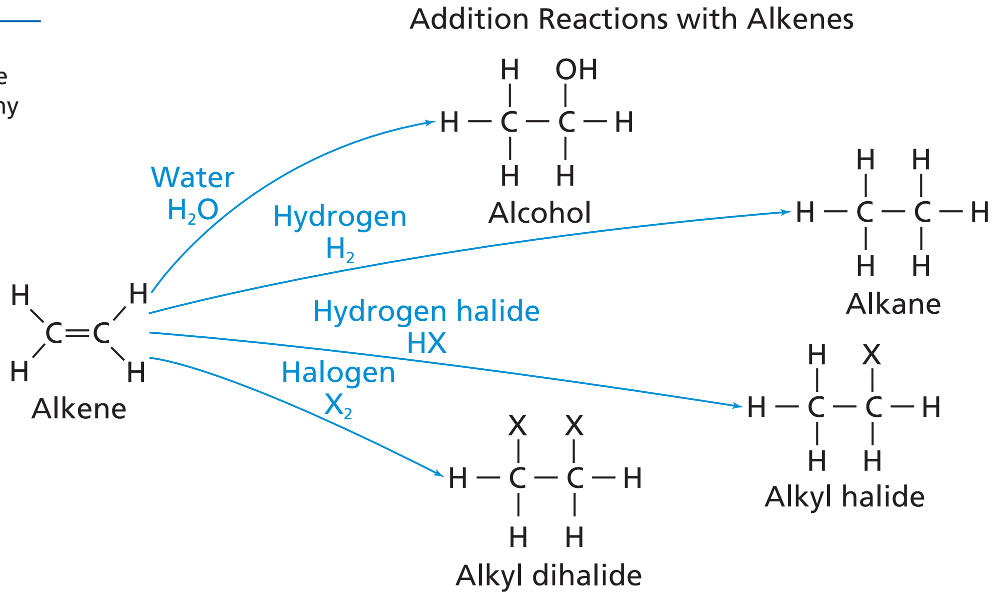
The generic form of this dehydration reaction can be written as follows.

$$R{-}CH_2{-}CH_2{-}OH \longrightarrow R{-}CH{=}CH_2 + H_2O$$

Addition reactions Another type of organic reaction appears to be an elimination reaction in reverse. An **addition reaction** results when other atoms bond to each of two atoms bonded by double or triple covalent bonds. Addition reactions typically involve double-bonded carbon atoms in alkenes or triple-bonded carbon atoms in alkynes. Addition reactions occur because double and triple bonds have a rich concentration of electrons. Therefore, molecules and ions that attract electrons tend to form bonds that use some of the electrons from the multiple bonds. The most

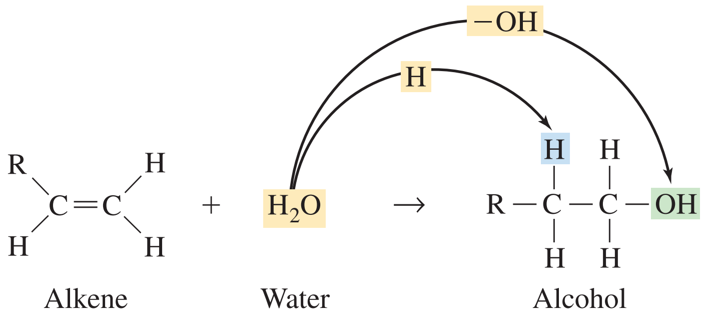
Figure 23-18

These examples are common addition reactions that can be carried out with alkenes. Many other addition reactions are possible.

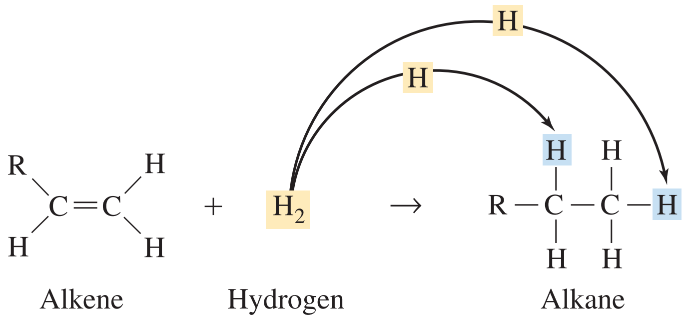


common addition reactions are those in which H_2O, H_2, HX, or X_2 add to an alkene as shown in **Figure 23-18.**

A **hydration reaction** is an addition reaction in which a hydrogen atom and a hydroxyl group from a water molecule add to a double or triple bond. As shown in the following generic example, a hydration reaction is the opposite of a dehydration reaction.



A reaction that involves the addition of hydrogen to atoms in a double or triple bond is called a **hydrogenation reaction.** This reaction is the reverse of one of the reactions you studied earlier in this section. Which one? One molecule of H_2 reacts to fully hydrogenate each double bond in a molecule. When H_2 adds to the double bond of an alkene, the alkene is converted to an alkane.



Catalysts are usually needed in the hydrogenation of alkenes because the reaction's activation energy is too large without them. Catalysts such as powdered platinum or palladium provide a surface that adsorbs the reactants and makes their electrons more available to bond to other atoms.

Hydrogenation reactions are commonly used to convert the liquid unsaturated fats found in oils from plants such as soybean, corn, and peanuts into saturated fats that are solid at room temperature. These hydrogenated fats are then used to make margarine and solid shortening. You will learn more about the composition of fats in Chapter 24.

Alkynes also may also be hydrogenated to produce alkenes or alkanes. Two molecules of H_2 must be added to each triple bond in order to convert an alkyne to an alkane, as shown in the following equations.

First H_2 molecule added

$$\underset{\text{Alkyne}}{R{-}C{\equiv}C{-}H + H_2} \rightarrow \underset{\text{Alkene}}{R{-}CH{=}CH_2}$$

Second H_2 molecule added

$$\underset{\text{Alkene}}{R{-}CH{=}CH_2 + H_2} \rightarrow \underset{\text{Alkane}}{R{-}CH_2{-}CH_3}$$

The addition of hydrogen halides to alkenes obtained from petroleum or natural gas is an addition reaction useful to industry for the production of alkyl halides.

$$\underset{\text{Alkene}}{R{-}CH{=}CH{-}R' + HX} \rightarrow \underset{\text{Alkyl halide}}{R{-}CHX{-}CH_2{-}R'}$$

As you learned earlier, R' is used to represent a second alkyl group. Chemists use the symbols R', R'', R''', and so on to represent different alkyl groups in organic molecules.

Do the **problem-solving LAB** below to learn how functional groups give organic compounds characteristic properties that may be used to identify a compound's general type.

problem-solving LAB

Categorizing Organic Compounds

Analyze and Conclude Functional groups give organic compounds distinct properties that may be used to identify the type of compound present. Suppose you examined the properties of several compounds and made the following observations.

Analysis

Compound 1 is a liquid that has a pungent odor. It is miscible with water, and the solution is a weak electrolyte.

Compound 2 is a crystalline solid with a melting point of 112°C and almost no odor. It is soluble in water, and chemical analysis shows that it contains nitrogen in addition to carbon, hydrogen and oxygen.

Compound 3 is a liquid that has a strong aroma resembling apricots. When spilled on a wood tabletop, it damages the finish.

Compound 4 is an oily-looking liquid with a disagreeable odor similar to a combination of ammonia and dead fish. It is soluble in water.

Thinking Critically

Use what you have learned about the properties of organic compounds with functional groups to suggest the category to which each compound belongs.

Figure 23-19

The oxidation of hydrocarbons provides the energy to run most of the vehicles on this crowded freeway.

Oxidation-reduction reactions Many organic compounds can be converted to other compounds by oxidation and reduction reactions. For example, suppose that you wish to convert methane, the main constituent of natural gas, to methanol, a common industrial solvent and raw material for making formaldehyde and methyl esters. The conversion of methane to methanol may be represented by the following equation, in which [O] represents oxygen from an agent such as copper(II) oxide, potassium dichromate, or sulfuric acid.

$$\begin{array}{c} \mathrm{H} \\ | \\ \mathrm{H-C-H} \\ | \\ \mathrm{H} \end{array} + [\mathrm{O}] \rightarrow \begin{array}{c} \mathrm{H} \\ | \\ \mathrm{H-C-O-H} \\ | \\ \mathrm{H} \end{array}$$

What happens to methane in this reaction? Before answering, it might be helpful to review the definitions of oxidation and reduction. Oxidation is the loss of electrons, and a substance is oxidized when it gains oxygen or loses hydrogen. Reduction is the gain of electrons, and a substance is reduced when it loses oxygen or gains hydrogen. Thus, methane is oxidized as it gains oxygen and is converted to methanol. Of course, every redox reaction involves both an oxidation and a reduction; however, organic redox reactions are described based on the change in the organic compound.

Oxidizing the methanol produced in the previous reaction is the first step in the sequence of reactions described by the following equations. For clarity, oxidizing agents are omitted.

$$\begin{array}{c} \mathrm{H} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{H} \end{array} \xrightarrow[\text{(loss of hydrogen)}]{\text{oxidation}} \begin{array}{c} \mathrm{O} \\ \| \\ \mathrm{H-C-H} \end{array} \xrightarrow[\text{(gain of oxygen)}]{\text{oxidation}} \begin{array}{c} \mathrm{O} \\ \| \\ \mathrm{H-C-OH} \end{array} \xrightarrow[\text{(loss of hydrogen)}]{\text{oxidation}} \mathrm{O{=}C{=}O}$$

Methanol (methyl alcohol) | Methanal (formaldehyde) | Methanoic acid (formic acid) | Carbon dioxide

Preparing an aldehyde by this method is not always a simple task because the oxidation may continue, forming the carboxylic acid. However, not all alcohols can be oxidized to aldehydes and, subsequently, carboxylic acids. To understand why, compare the oxidations of 1-propanol and 2-propanol shown in the following equations.

$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{H-C-CH_2-CH_3} \\ | \\ \mathrm{H} \end{array} + [\mathrm{O}] \rightarrow \begin{array}{c} \mathrm{O} \\ \| \\ \mathrm{H-C-CH_2-CH_3} \end{array}$$

1-Propanol → Propanal

$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{CH_3-C-CH_3} \\ | \\ \mathrm{H} \end{array} + [\mathrm{O}] \rightarrow \begin{array}{c} \mathrm{O} \\ \| \\ \mathrm{CH_3-C-CH_3} \end{array}$$

2-Propanol → 2-Propanone

Figure 23-20

Organic oxidation-reduction reactions provide the energy that these students need to live and play active sports such as basketball.

Note that oxidizing 2-propanol yields a ketone, not an aldehyde. Unlike aldehydes, ketones resist further oxidation to carboxylic acids. Thus, while the propanal formed by oxidizing 1-propanol easily oxidizes to form propanoic acid, the 2-propanone formed by oxidizing 2-propanol does not react to form a carboxylic acid.

How important are organic oxidations and reductions? You've seen that oxidation and reduction reactions can change one functional group into another. That ability enables chemists to use organic redox reactions, in conjunction with the substitution and addition reactions you learned about earlier in the chapter, to synthesize a tremendous variety of useful products. On a personal note, living systems—including you—depend on the energy released by oxidation reactions. Of course, some of the most dramatic oxidation-reduction reactions are combustion reactions. All organic compounds that contain carbon and hydrogen burn in excess oxygen to produce carbon dioxide and water. For example, the highly exothermic combustion of ethane is described by the following thermochemical equation.

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l) \qquad \Delta H = -3.21 \text{ kJ}$$

As you learned in Chapter 10, much of the world relies on the combustion of hydrocarbons as a primary source of energy. Our reliance on the energy from organic oxidation reactions is illustrated in **Figures 23-19** and **23-20.**

Predicting Products of Organic Reactions

The generic equations representing the different types of organic reactions you have learned—substitution, elimination, addition, oxidation-reduction, and condensation—can be used to predict the products of other organic reactions of the same types. For example, suppose you were asked to predict the product of an elimination reaction in which 1-butanol is a reactant. You know that a common elimination reaction involving an alcohol is a dehydration reaction.

The generic equation for the dehydration of an alcohol is

$$R{-}CH_2{-}CH_2{-}OH \rightarrow R{-}CH{=}CH_2 + H_2O$$

To determine the actual product, first draw the structure of 1-butanol. Then use the generic equation as a model to see how 1-butanol would react.

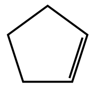
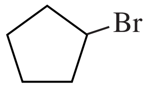
From the generic reaction, you can see that only the carbon bonded to the $-OH$ and the carbon next to it react. Finally, draw the structure of the likely products as shown in the following equation. Your result should be the following equation.

$$\underset{\text{1-Butanol}}{CH_3{-}CH_2{-}CH_2{-}CH_2{-}OH} \rightarrow \underset{\text{1-Butene}}{CH_3{-}CH_2{-}CH{=}CH_2} + H_2O$$

As another example, suppose that you wish to predict the product of the reaction between cyclopentene and hydrogen bromide. Recall that the generic equation for an addition reaction between an alkene and an alkyl halide is as follows.

$$R-CH=CH-R' + HX \rightarrow R-CHX-CH_2-R'$$

First, draw the structure for cyclopentene, the organic reactant, and add the formula for hydrogen bromide, the other reactant. From the generic equation, you can see that a hydrogen atom and a halide atom add across the double bond to form an alkyl halide. Finally, draw the formula for the likely product. If you are correct, you have written the following equation.

 + HBr → 

Cyclopentene Hydrogen bromide Bromocyclopentane

Section 23.4 Assessment

20. Classify each of the following reactions as either substitution, elimination, addition, or condensation.

a. $CH_3CH{=}CHCH_2CH_3 + H_2 \rightarrow CH_3CH_2{-}CH_2CH_2CH_3$

b. $\underset{\displaystyle\; |\atop OH}{CH_3CH_2CH_2CHCH_3} \rightarrow CH_3CH_2CH{=}CHCH_3 + H_2O$

c. $CH_3CH_2C{\equiv}CCH_3 + 2H_2 \rightarrow$

d. $\underset{\displaystyle |\atop OH}{CH_3CH_2CHCH_2CH_3} \xrightarrow{\text{Dehydration}}$

21. Identify the type of organic reaction that would best accomplish each of the following conversions.

a. alkyl halide ⟶ alkene

b. alkene ⟶ alcohol

c. alcohol + carboxylic acid ⟶ ester

22. Complete each of the following equations by writing the condensed structural formula for the product that is most likely to form.

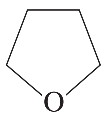
a. $CH_3CH{=}CHCH_2CH_3 + H_2 \rightarrow$

b. $\underset{\displaystyle |\atop Cl}{CH_3CH_2CHCH_2CH_3} + OH^- \rightarrow$

23. Thinking Critically Explain why the hydration reaction involving 1-butene may yield two distinct products whereas the hydration of 2-butene yields but one product.

24. Comparing and Contrasting Explain the difference between an elimination reaction and a condensation reaction. Which type is best represented by the following equation?

$$HO-CH_2CH_2CH_2CH_2-OH \rightarrow$$

 + H_2O

Section 23.5

Polymers

Think how different your life would be without plastic sandwich bags, plastic foam cups, nylon and polyester fabrics, vinyl siding on buildings, foam cushions, and a variety of other synthetic materials. Synthetic materials do not exist in nature; they are produced by the chemical industry.

Objectives

- **Describe** the relationship between a polymer and the monomers from which it forms.
- **Classify** polymerization reactions as addition or condensation.
- **Predict** polymer properties based on their molecular structures and the presence of functional groups.

Vocabulary

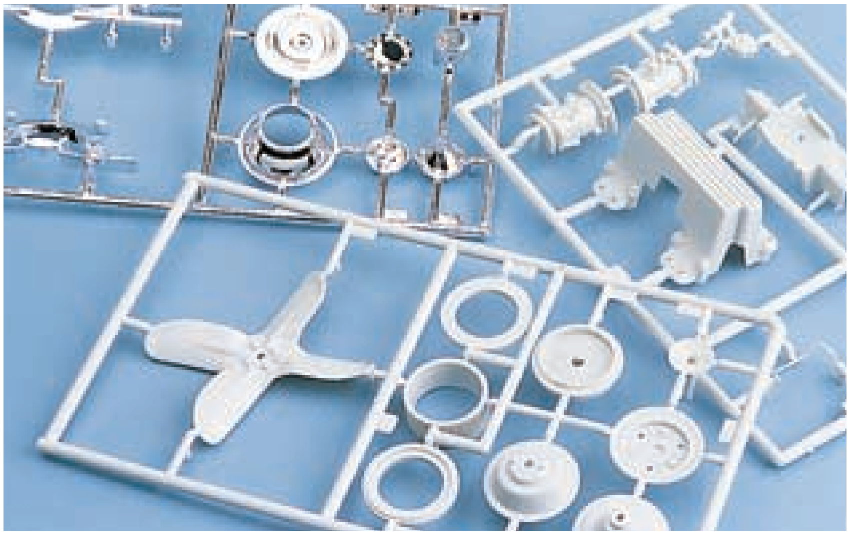
polymer
monomer
polymerization reaction
addition polymerization
condensation polymerization
plastic
thermoplastic
thermosetting

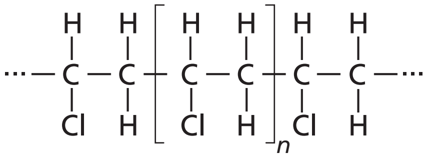
The Age of Polymers

The structural formulas shown in **Figure 23-21** represent extremely long molecules having groups of atoms that repeat in a regular pattern. These molecules are examples of synthetic polymers. **Polymers** are large molecules consisting of many repeating structural units. The letter *n* represents the number of structural units in the polymer chain. Because polymer *n* values vary widely, molecular masses of polymers range from less than 10 000 amu to more than 1 000 000 amu. A typical Teflon chain has about 400 units, giving it a molecular mass of around 40 000 amu.

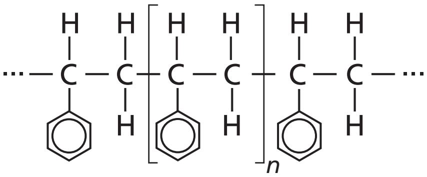
Before the development of synthetic polymers, people were limited to using natural substances such as stone, wood, metals, wool, and cotton. By the turn of the twentieth century, a few chemically treated natural polymers such as rubber and the first plastic, celluloid, had become available. Celluloid is made by treating cellulose from cotton or wood fiber with nitric acid.

The first synthetic polymer was Bakelite, synthesized in 1909. Bakelite is still used today in stove-top appliances because of its resistance to heat. Since 1909, hundreds of other synthetic polymers have been developed. In the future, people may refer to this time as the Age of Polymers.





a Polyvinyl chloride



b Polystyrene

Figure 23-21

a The polymer polyvinyl chloride is commonly called "vinyl." It is used to make flexible, waterproof objects. b Polystyrene plastic is inexpensive and easy to mold into parts for model cars and airplanes.

Reactions Used to Make Polymers

Polymers are relatively easy to manufacture. They usually can be synthesized in one step in which the major reactant is a substance consisting of small, simple organic molecules called monomers. A **monomer** is a molecule from which a polymer is made.

When a polymer is made, monomers bond together one after another in a rapid series of steps. A catalyst usually is required for the reaction to take place at a reasonable pace. With some polymers, such as Dacron and nylon, two or more kinds of monomers bond to each other in an alternating sequence. A reaction in which monomer units are bonded together to form a polymer is called a **polymerization reaction**. The repeating group of atoms formed by the bonding of the monomers is called the structural unit of the polymer. The structural unit of a polymer made from two different monomers has the components of both monomers.

Unbreakable children's toys are often made of polyethylene, which is synthesized by polymerizing ethene under pressure. Two monomers react to form polyethylene terephthalate (PET), a versatile plastic that is used to make bottles and recording tape. When made into fiber, it is called Dacron. Polyethylene and PET, examples of polymers made by two types of reactions, are shown in **Table 23-3.**

Careers Using Chemistry

Dental Assistant

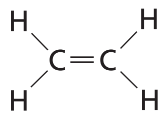
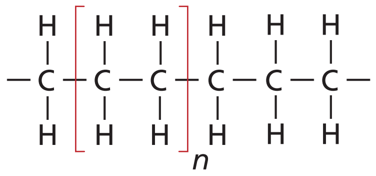
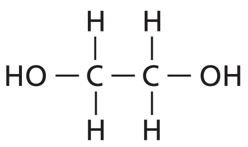
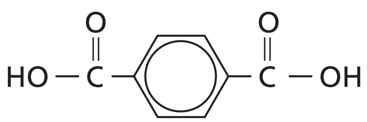
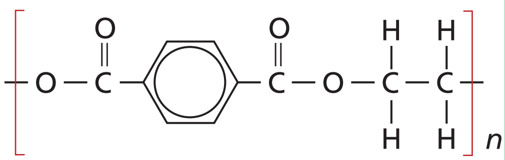
Would you like to mix polymers, process X rays, and in other ways help a dentist care for people's teeth? If so, you might become a dental assistant.

While dental hygienists clean teeth, dental assistants work directly with the dentist. They prepare and sterilize instruments, remove sutures, mix adhesives, prepare fillings, make casts of teeth, and create temporary crowns. Some assistants also keep treatment records and schedule patient appointments.

Addition polymerization In **addition polymerization,** all of the atoms present in the monomers are retained in the polymer product. When the monomer is ethene, an addition polymerization results in the polymer polyethylene, as shown in **Table 23-3.** Unsaturated bonds are broken in addition polymerization just as they are in addition reactions. The difference is that

Table 23-3

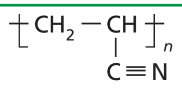
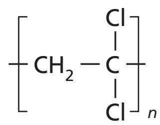
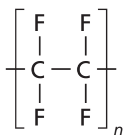
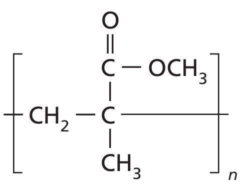
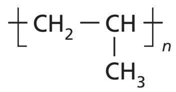
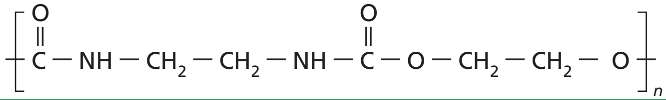
Monomers and Polymers

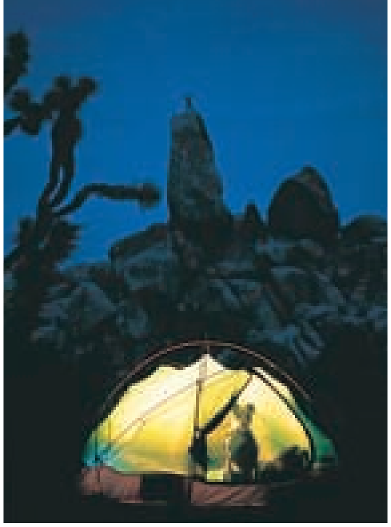
Monomer(s)	Structural unit of polymer	Application
 Ethene (ethylene)	 Polyethylene	
 1,2-Ethanediol (ethylene glycol)  Terephthalic acid	 Polyethylene terephthalate (Dacron in fiber form) (Mylar in film form)	

the molecule added is a second molecule of the same substance, ethene. Note that the addition polymers in **Table 23-4** are similar in structure to polyethylene. That is, the molecular structure of each is equivalent to polyethylene in which other atoms or groups of atoms are attached to the chain in place of hydrogen atoms. All of these polymers are made by addition polymerization.

Table 23-4

Common Polymers

Polymer	Uses	Structural unit
Polyethylene (PE)	Plastic bags and wrap, food containers, children's toys, bottles	See **Table 23-3.**
Polyvinyl chloride (PVC)	Plastic pipes, meat wrap, upholstery, rainwear, house siding, garden hose	See **Figure 23-21.**
Polyacrylonitrile (Orlon)	Fabrics for clothing and upholstery, carpet	
Polyvinylidene chloride (Saran)	Food wrap, fabrics	
Polytetrafluoro-ethylene (Teflon, PTFE)	Nonstick coatings, bearings, lubricants	
Polymethyl methacrylate (Lucite, Plexiglass)	"Nonbreakable" windows, inexpensive lenses, art objects	
Polypropylene (PP)	Beverage containers, rope, netting, kitchen appliances	
Polystyrene styrene plastic	Foam packing and insulation, plant pots, disposable food containers, model kits	See **Figure 23-21.**
Polyethylene terephthalate (PET, Dacron, Mylar)	Soft drink bottles, tire cord, clothing, recording tape, replacements for blood vessels	See **Table 23-3.**
Nylon	Upholstery, clothing, carpet, fishing line, small gears, bearings	See **Figure 23-22.**
Polyurethane	Foam furniture cushions, waterproof coatings, parts of shoes	



Condensation polymerization **Condensation polymerization** takes place when monomers containing at least two functional groups combine with the loss of a small by-product, usually water. Nylon and Kevlar are made this way. Nylon was first synthesized in 1931 and soon became popular because it is strong and can be drawn into thin strands resembling silk. Nylon-6,6 is the name of one type of nylon that is synthesized from two different six-carbon monomers. One monomer is a chain with the end carbon atoms being part of carboxyl groups. The other monomer is a chain having amino groups at both ends. These monomers undergo a condensation polymerization that forms amide groups linking the subunits of the polymer, as shown by the tinted –NH– group in **Figure 23-22.** Note that one water molecule is released for every new amide bond formed.

$$\underset{\text{Adipic acid}}{n\mathrm{HOOC{-}(CH_2)_4{-}COOH}} + \underset{\text{1,6–Diamino hexane}}{n\mathrm{H_2N{-}(CH_2)_6{-}NH_2}} \rightarrow \underset{\text{Nylon – 6,6}}{\left[\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{{-}(CH_2)_4{-}}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{{-}NH{-}(CH_2)_6{-}NH}\right]_n} + n\mathrm{H_2O}$$

Figure 23-22

Adipic acid and 1,6-diaminohexane are the monomers that polymerize by condensation to form nylon-6,6. You are probably familiar with nylon fabrics, such as those used to make tents, but nylon can be molded into solid objects too.

Materials Made from Polymers: Uses and Recycling

Why do we use so many different polymers today? One reason is that they are easy to synthesize. Another reason is that the starting materials used to make them are inexpensive. Still another, more important, reason is that polymers have a wide range of properties. Some polymers can be drawn into fine fibers that are softer than silk, while others are as strong as steel. Polymers don't rust like steel does, and many are more durable than natural materials such as wood. Objects made from lumber that is actually plastic, such as those shown in **Figure 23-23,** may be familiar to you.

Properties of polymers Another reason that polymers are in such great demand is that it is easy to mold them into different shapes or to draw them into thin fibers. It is not easy to do this with metals and other natural materials because either they must be heated to high temperatures, do not melt at all, or are too weak to be used to form small, thin items. A **plastic** is a polymer that can be heated and molded while relatively soft.

As with all substances, polymers have properties that result directly from their molecular structure. For example, polyethylene is a long-chain alkane. Thus, it has a waxy feel, does not dissolve in water, is nonreactive, and is a poor electrical conductor. These properties make it ideal for use in food and beverage containers and as an insulator on electrical wire and TV cable.

Polymers fall into two different categories based on their melting characteristics. A **thermoplastic** polymer is one that can be melted and molded repeatedly into shapes that are retained when it is cooled. Polyethylene and nylon are examples of thermoplastic polymers. A **thermosetting** polymer is one that can be molded when it is first prepared, but when cool cannot be remelted. This property is explained by the fact that thermosetting polymers begin to form networks of bonds in many directions when they are synthesized. By the time they have cooled, thermosetting polymers have become, in essence, a single large molecule. Bakelite is an example of a thermosetting polymer. Instead of melting, Bakelite decomposes or burns when overheated.

Figure 23-23

Plastic lumber is made from recycled plastic, especially soft drink bottles and polyethylene waste.

Figure 23-24

These codes tell recyclers what kind of plastic an object is made of.

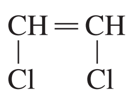
Recycling polymers The starting materials for the synthesis of most polymers are derived from fossil fuels. As the supply of fossil fuels is depleted, recycling plastics will become more important. Thermosetting polymers are more difficult to recycle than thermoplastic polymers because only thermoplastic materials can be melted and remolded repeatedly.

Currently, only about 1% of the plastic waste we produce in the United States is recycled. This figure contrasts with the 20% of paper waste and 30% of aluminum waste that are recycled. This low rate of plastics recycling is due in part to the large variety of different plastics found in products. The plastics must be sorted according to polymer composition. This task is time-consuming and expensive. The plastics industry and the government have tried to improve the process by providing standardized codes that indicate the composition of each plastic product. See **Figure 23-24.**

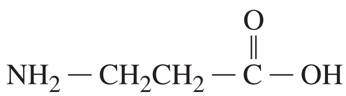
Section 23.5 Assessment

25. Draw the structure for the polymer that could be produced from each of the following monomers by the method stated.

a. Addition

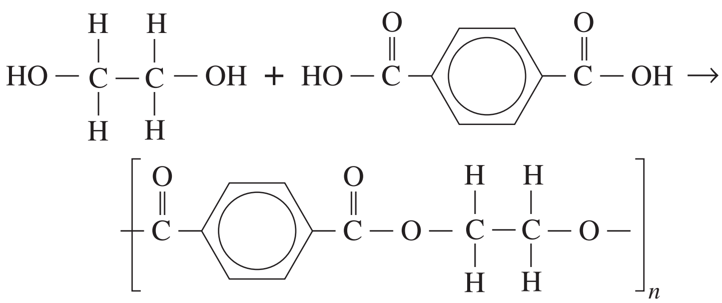


b. Condensation

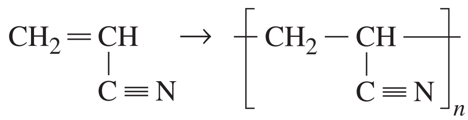


26. Label each of the following polymerization reactions as addition or condensation. Write the formulas of the secondary product of the condensation reaction.

a.



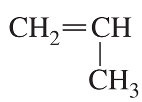
b.



27. Compare the properties of thermosetting and thermoplastic polymers.

28. Thinking Critically A chemical process called crosslinking forms covalent bonds between separate polymer chains. How do you think a polymer's properties will change as the number of crosslinks increases? What effect might additional crosslinking have on a thermoplastic polymer?

29. Predicting Predict the physical properties of the polymer that is made from the following monomer. Mention solubility in water, electrical conductivity, texture, and chemical reactivity. Do you think it will be thermoplastic or thermosetting? Give reasons for your predictions.



CONTENTS

CHEMLAB 23

Properties of Alcohols

Alcohols are organic compounds that contain the $-OH$ functional group. In this experiment, you will determine the strength of intermolecular forces of alcohols by determining how fast various alcohols evaporate. The evaporation of a liquid is an endothermic process, absorbing energy from the surroundings. This means that the temperature will decrease as evaporation occurs.

Problem

How do intermolecular forces differ in three alcohols?

Objectives

- **Measure** the rate of evaporation for water and several alcohols.
- **Infer** the relative strength of intermolecular forces of alcohols from rate of evaporation data.

Materials

thermometer
stopwatch
facial tissue
cloth towel
Beral pipettes (5)
methanol
ethanol (95%)
2-propanol (99%)
wire twist tie or small rubber band
piece of cardboard for use as a fan

Safety Precautions

- **Always wear safety goggles and a lab apron.**
- **The alcohols are flammable. Keep them away from open flames.**

Pre-Lab

1. Read the entire **CHEMLAB.**
2. Prepare all written materials that you will take into the laboratory. Be sure to include safety precautions, procedure notes, and a data table.
3. Draw structural formulas for the three alcohols you will use in this activity. Describe how the structures of these compounds are alike and how they are different.
4. What types of forces exist between these kinds of molecules? Suggest which alcohol may have the greatest intermolecular forces.

Evaporation Data

Substance	Starting temp (°C)	Temp after one minute (°C)	ΔT (°C)
Water			
Methanol			
Ethanol			
2-Propanol			
Other alcohol			

Procedure

1. Cut out five 2-cm by 6-cm strips of tissue.
2. Place a thermometer on a folded towel lying on a flat table so that the bulb of the thermometer extends over the edge of the table. Make sure the thermometer cannot roll off the table.
3. Wrap a strip of tissue around the bulb of the thermometer. Secure the tissue with a wire twist tie placed above the bulb of the thermometer.
4. Choose one person to control the stopwatch and read the temperature on the thermometer. A second person will put a small amount of the liquid to be tested into a Beral pipette.
5. When both people are ready, squeeze enough liquid onto the tissue to completely saturate it. At the same time, the other person starts the stopwatch, reads the temperature, and records it in the data table.
6. Fan the tissue-covered thermometer bulb with a piece of cardboard or other stiff paper. After one minute, read and record the final temperature in the data table. Remove the tissue and wipe the bulb dry.

7. Repeat steps 3 through 6, for each of the three alcohols: methanol, ethanol, and 2-propanol. If your teacher has another alcohol, use it also.

Cleanup and Disposal

1. Place tissues in the trash. Pipettes can be reused.

Analyze and Conclude

1. **Communicating** Formulate a statement that summarizes your data, relating temperature change to the substances tested. Do not draw any conclusions yet.
2. **Acquiring and Analyzing Information** Explain why the temperatures changed during the experiment.
3. **Observing and Inferring** What can you conclude about the relationship between heat transfer and the differences in the temperature changes you observed?
4. **Drawing Conclusions** Assume that the three alcohols have approximately the same molar enthalpy of vaporization. What can you say about the relative rates of evaporation of the three alcohols?
5. **Drawing Conclusions** Consider your answer to question 4. What can you conclude about the relative strength of intermolecular forces existing in the three alcohols?
6. **Predicting** Suppose you also tested the alcohol 1-pentanol in this experiment. Where among the alcohols tested would you predict 1-pentanol to rank in rate of evaporation from fastest to slowest? Describe the temperature change you would expect to observe. Explain your reasoning.
7. **Thinking Critically** Molar enthalpies of vaporization for the three alcohols are given in the table below. Note that they are not the same.

Molar Enthalpies of Vaporization

Substance	Enthalpy of vaporization at 25°C (kJ/mol)
Methanol	37.4
Ethanol	42.3
2-Propanol	45.4

   In what way, if any, does this data change your conclusion about intermolecular forces?
8. **Observing and Inferring** Make a general statement comparing the molecular size of an alcohol in terms of the number of carbons in the carbon chain to the rate of evaporation of that alcohol.
9. **Error Analysis** Suggest a way to make this experiment more quantitative and controlled.

Real-World Chemistry

1. How can this experiment help explain why small-chain alcohols have a warning label indicating that they are flammable?
2. Would you expect to see such a warning label on a bottle of 1-decanol? Explain.
3. A mixture of 70% 2-propanol (isopropanol) and 30% water is sold as rubbing alcohol, which may be used to help reduce a fever. Explain how this process works.
4. Why do you suppose that 2-propanol is a component in some products used to soothe sunburned skin?

CHEMISTRY and Technology

Carbon: Stronger than Steel?

If you play golf or tennis, fish or ride a bicycle, chances are good that you have used carbon-fiber technology. In the 1960s, the aerospace industry began searching for structural materials that were as strong as metals but were light in weight because making space vehicles lighter meant that larger satellites or more experimental equipment could be lifted into space with the same amount of fuel. At about the same time, the petroleum industry showed that it could make fibers that were nearly pure carbon. Carbon fibers are stronger than steel when pulled at the ends, but they break when bent sharply. Engineers solved this problem by making a mat with carbon fibers oriented in all directions. Embedding the mat in a plastic matrix produced sheets of extremely strong but lightweight material. Such a material—a mixture of two or more materials that produces a combination stronger than the materials alone—is called a composite material.

From Spacecraft to Sports

Carbon fibers are expensive to make, but their cost has decreased steadily. In the 1980s, a few expensive consumer items were produced, beginning with golf clubs having carbon-fiber-reinforced shafts. Then came tennis rackets, fishing rods, skis, and snowboards. Today, bicycles with frames made of carbon fiber are becoming increasingly popular. These frames are about 40% lighter than similar frames made of metal tubing. With lighter frames, riders use less energy to go the same distance. In the aircraft industry, less weight means fuel savings, so more and more parts such as seat frames and structural panels are being manufactured from carbon fiber.

Making Carbon Fibers

Carbon fibers are polymers composed of long chains of carbon atoms in aromatic rings. Each carbon fiber is composed of narrow sheets that are extremely long. How do you polymerize carbon atoms?

Manufacturers first produce fibers of a synthetic polymer called polyacrylonitrile, or PAN. PAN fibers are heated intensely in an oxygen-free atmosphere, driving off all hydrogen, oxygen, and nitrogen atoms. After this process, the fiber consists of only carbon atoms with strong, stable bonds that give carbon fibers their great strength.

The Future of Carbon Fibers

Other possible applications of carbon-fiber composites include prosthetic limbs, musical instruments, sports helmets and other protective gear, lightweight building materials, and reinforcing beams used to repair aging bridges. Because carbon fibers conduct electricity, scientists and engineers are working to find ways to incorporate electronic circuits into structural materials.

Investigating the Technology

1. **Using Resources** What advantages might carbon fiber have over metals in artificial limbs?

CHEMISTRY Online

CLICK HERE

Visit the Chemistry Web site at **science.glencoe.com** to find links about carbon fiber composites.

Summary

23.1 Functional Groups

- Carbon forms bonds with atoms other than C and H, especially O, N, S, P, F, Cl, Br, and I.
- An atom or group of atoms that always react in a certain way in an organic molecule is referred to as a functional group.
- An alkyl halide is an organic compound that has one or more halogen atoms (F, Cl, Br, or I) bonded to a carbon atom.

23.2 Alcohols, Ethers, and Amines

- An alcohol is an organic compound that has an –OH group bonded to a carbon atom.
- Because they readily form hydrogen bonds, alcohols have higher boiling points and higher water solubilities than other organic compounds.
- Alcohols are used as solvents and as starting materials in synthesis reactions, medicinal products, and the food and beverage industries.
- An amine is an organic compound that contains a nitrogen atom bonded to one or more carbon atoms.
- An ether is an organic compound having the R—O—R' structure.

23.3 Carbonyl Compounds

- Carbonyl compounds are organic compounds that contain the C=O group.
- Five important classes of organic compounds containing carbonyl compounds are aldehydes, ketones, carboxylic acids, esters, and amides.

23.4 Other Reactions of Organic Compounds

- Most reactions of organic compounds can be classified into one of five categories: substitution; elimination; addition; oxidation-reduction; condensation.
- Knowing the types of organic compounds reacting may enable you to predict the reaction products.

23.5 Polymers

- Polymers are large molecules formed by combining smaller molecules called monomers.
- Polymers are synthesized through addition or condensation reactions.
- The functional groups present in polymers can be used to predict polymer properties.

Vocabulary

- addition polymerization (p. 762)
- addition reaction (p. 755)
- alcohol (p. 743)
- aldehyde (p. 747)
- alkyl halide (p. 738)
- amide (p. 752)
- amine (p. 745)
- aryl halide (p. 739)
- condensation polymerization (p. 764)
- condensation reaction (p. 753)
- carbonyl group (p. 747)
- carboxylic acid (p. 749)
- carboxyl group (p. 749)
- dehydration reaction (p. 755)
- dehydrogenation reaction (p. 754)
- denatured alcohol (p. 744)
- elimination reaction (p. 754)
- ester (p. 750)
- ether (p. 745)
- functional group (p. 737)
- halocarbon (p. 738)
- halogenation (p. 741)
- hydration reaction (p. 756)
- hydrogenation reaction (p. 756)
- hydroxyl group (p. 743)
- ketone (p. 748)
- monomer (p. 762)
- plastic (p. 764)
- polymer (p. 761)
- polymerization reaction (p. 762)
- substitution reaction (p. 741)
- thermoplastic (p. 764)
- thermosetting (p. 764)

CHAPTER 23 ASSESSMENT

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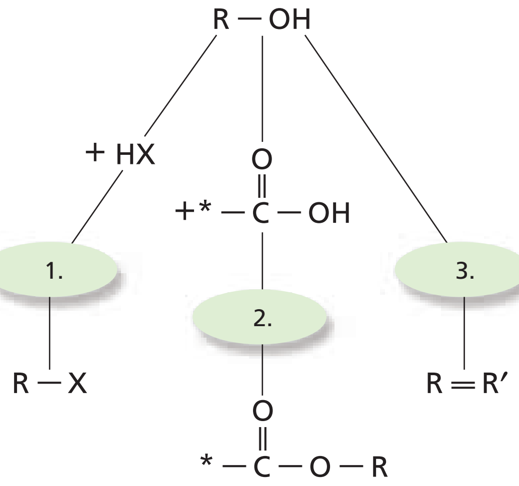
Concept Mapping

30. Identify the types of reactions used to convert alcohols into alkyl halides, esters, and alkenes.



Mastering Concepts

31. What is a functional group? (23.1)

32. Describe and compare the structures of alkyl halides and aryl halides. (23.1)

33. What reactant would you use to convert methane to bromomethane? (23.1)

34. Name the amines represented by the condensed formulas below. (23.2)

a. $CH_3(CH_2)_3CH_2NH_2$
b. $CH_3(CH_2)_5CH_2NH_2$
c. $CH_3(CH_2)_2CH(NH_2)CH_3$
d. $CH_3(CH_2)_8CH_2NH_2$

35. How is ethanol denatured? (23.2)

36. Name one alcohol, amine, or ether that is used for each of the following purposes. (23.2)

a. antiseptic
b. solvent in paint strippers
c. antifreeze
d. anesthetic
e. dye production

37. Explain why an alcohol molecule will always have a higher solubility in water than an ether molecule having an identical molecular mass. (23.2)

38. Explain why ethanol has a much higher boiling point than aminoethane even though their molecular masses are nearly equal. (23.2)

39. Draw the general structure for each of the following classes of organic compounds. (23.3)

a. aldehyde
b. ketone
c. carboxylic acid
d. ester
e. amide

40. Name an aldehyde, ketone, carboxylic acid, ester, or amide used for each of the following purposes. (23.3)

a. preserving biological specimens
b. solvent in fingernail polish
c. acid in vinegar
d. flavoring in foods and beverages

41. What type of reaction is used to produce aspirin from salicylic acid and acetic acid? (23.3)

42. What is the starting material for making most synthetic organic compounds? (23.4)

43. Explain the importance of classifying reactions. (23.4)

44. List the type of organic reaction needed to carry out each of the following transformations. (23.4)

a. alkene ⟶ alkane
b. alkyl halide ⟶ alcohol
c. alkyl halide ⟶ alkene
d. amine + carboxylic acid ⟶ amide
e. alcohol ⟶ alkyl halide
f. alkene ⟶ alcohol

45. Explain the difference between addition polymerization and condensation polymerization. (23.5)

46. Which type of polymer is easier to recycle, thermosetting or thermoplastic? Explain your answer. (23.5)

Mastering Problems

Functional Groups (23.1)

47. Draw structures for these alkyl and aryl halides.

a. chlorobenzene
b. 1-bromo-4-chlorohexane
c. 1,2-difluoro-3-iodocyclohexane
d. 1, 3-dibromobenzene
e. 1,1,2,2-tetrafluoroethane

48. For 1-bromo-2-chloropropane:

a. Draw the structure.
b. Does the compound have optical isomers?
c. If the compound has optical isomers, identify the chiral carbon atom.

49. Name one structural isomer created by changing the position of one or more halogen atoms in each alkyl halide.

a. 2-chloropentane
b. 1,1-difluropropane
c. 1,3-dibromocyclopentane
d. 1-bromo-2-chloroethane

Alcohols, Ethers, and Amines (23.2)

50. Name one ether that is a structural isomer of each alcohol.

a. 1-butanol **b.** 2-hexanol

51. Draw structures for the following alcohol, amine, and ether molecules.

a. 1,2-butanediol
b. 5-aminohexane
c. isopropyl ether
d. 2-methyl-1-butanol
e. butyl pentyl ether
f. cyclobutyl methyl ether
g. 1,3-diaminobutane
h. cyclopentanol

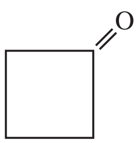
Carbonyl Compounds (23.3)

52. Draw structures for each of the following carbonyl compounds.

a. 2,2-dichloro-3-pentanone
b. 4-methylpentanal
c. isopropyl hexanoate
d. octanoamide
e. 3-fluoro-2-methylbutanoic acid
f. cyclopentanal
g. hexyl methanoate

53. Name each of the following carbonyl compounds.

a.



b. $CH_3-CH_2-CH_2-\overset{\overset{\large O}{\|}}{C}-H$

c. $CH_3 + CH_2 +_4 \overset{\overset{\large O}{\|}}{C} - OH$

d. $CH_3 + CH_2 +_4 \overset{\overset{\large O}{\|}}{C} - NH_2$

Other Reactions of Organic Compounds (23.4)

54. Classify each of the following organic reactions as substitution, addition, elimination, oxidation-reduction or condensation.

a. 2-butene + hydrogen ⟶ butane
b. propane + fluorine ⟶ 2-fluoropropane + hydrogen fluoride
c. 2-propanol ⟶ propene + water
d. cyclobutene + water ⟶ cyclobutanol

55. Use structural formulas to write equations for the following reactions.

a. the substitution reaction between 2-chloropropane and water yielding 2-propanol and hydrogen chloride
b. the addition reaction between 3-hexene and chlorine yielding 3,4-dichlorohexane

56. What type of reaction converts an alcohol into each of the following types of compounds?

a. ester **c.** alkene
b. alkyl halide **d.** aldehyde

57. Use structural formulas to write the equation for the condensation reaction between ethanol and propanoic acid.

Polymers (23.5)

58. What monomers react to make each polymer?

a. polyethylene **c.** Teflon
b. Dacron **d.** Nylon 6,6

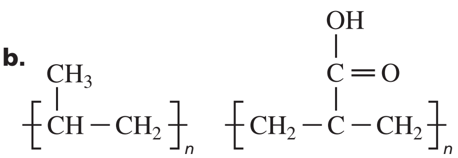
59. Name the polymers made from the following monomers.

a. $CF_2{=}CF_2$ **b.** $CH_2{=}CCl_2$

60. Choose the polymer of each pair that you expect to have the higher water solubility.

a. $\left[CH_2-CH_2 \right]_n$ $\left[CH_2-\underset{\underset{\large OH}{|}}{CH} \right]_n$

b.



I II

CHAPTER 23 ASSESSMENT

61. Examine the structures of the following polymers in **Table 23-4.** Decide whether each is made by addition or condensation polymerization.

a. nylon
b. polyacrylonitrile
c. polyurethane
d. polypropylene

Mixed Review

Sharpen your problem-solving skills by answering the following.

62. Which halogen is found in hormones made by a normal human thyroid gland?

63. Describe the properties of carboxylic acids.

64. List two uses of esters.

65. Draw structures of the following compounds. (23.3)

a. butanone
b. propanal
c. hexanoic acid
d. heptanoamide
e. ethyl pentanoate
f. benzoic acid

66. Name the type of organic compound formed by each of the following reactions.

a. elimination from an alcohol
b. addition of hydrogen chloride to an alkene
c. addition of water to an alkene
d. substitution of a hydroxyl group for a halogen atom

67. List two uses for each of the following polymers.

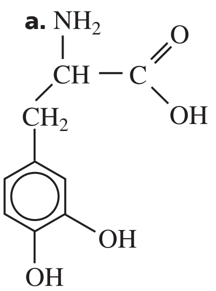
a. polypropylene
b. polyurethane
c. polytetrafluoroethylene
d. polyvinyl chloride

68. Draw structures of and supply names for the organic compounds produced by reacting ethene with each of the following substances.

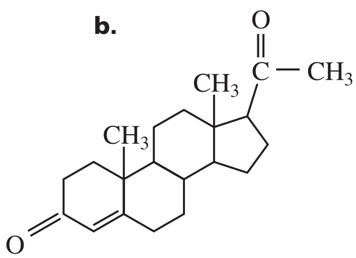
a. water
b. hydrogen
c. hydrogen chloride
d. fluorine

Thinking Critically

69. Intrepreting Scientifc Illustrations List all the functional groups present in each of the following complex organic molecules.

a.


Levadopa

b.


Progesterone

70. Thinking Critically Ethanoic acid (acetic acid) is very soluble in water. However, naturally occurring long-chain carboxylic acids such as palmitic acid ($CH_3(CH_2)_{14}COOH$) are insoluble in water. Explain.

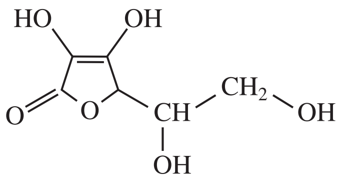
71. Communicating Write structural formulas for all structural isomers of molecules having the following formulas. Name each isomer.

a. C_3H_8O **b.** $C_2H_4Cl_2$ **c.** C_3H_6

72. Recognizing Cause and Effect Arrange the following compounds in order of increasing boiling point.

butanol, butane, 1-aminobutane, ethyl ether

73. Intrepreting Scientifc Illustrations Human cells require vitamin C to properly synthesize materials that make up connective tissue such as that found in ligaments. List the functional groups present in the Vitamin C molecule.



Vitamin C

Writing in Chemistry

74. While living organisms have made polymers like cotton, silk, wool, and latex rubber for thousands of years, the first laboratory synthesis of a polymer occurred only in the late 1800s. Imagine that you live in the 1880s, before society entered what some chemists refer to as the "Age of Polymers." Write a short story describing how your life would differ from its present form because of the absence of synthetic polymers.

Cumulative Review

Refresh your understanding of previous chapters by answering the following.

75. Why do the following characteristics apply to transition metals? (Chapter 7)

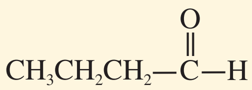
a. Ions vary in charge.
b. Many of their solids are colored.
c. Many are hard solids.

76. What is a rate-determining step? (Chapter 17)

77. According to Le Châtelier's principle, how would increasing the volume of the reaction vessel affect the equilibrium $2SO_2(g) + O_2(g) \rightleftarrows 2SO_3(g)$? (Chapter 18)

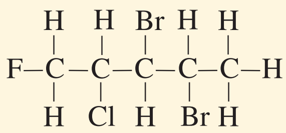
Use these questions and the test-taking tip to prepare for your standardized test.

1. The compound pictured below is _____ .



a. an aldehyde **c.** a ketone
b. an ether **d.** an alcohol

2. The name of the compound shown is _____ .



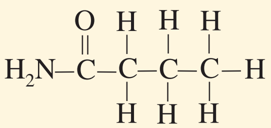
a. 2-chloro-3,4-dibromo-1-fluoropentane
b. 4-chloro-2,3-dibromo-5-fluoropentane
c. 3,4-dibromo-2-chloro-1-fluoropentane
d. 2,3-dibromo-4-chloro-5-fluoropentane

3. The products of this reaction are _____ .

$CH_3CH_2CH_2Br + NH_3 \rightarrow ?$

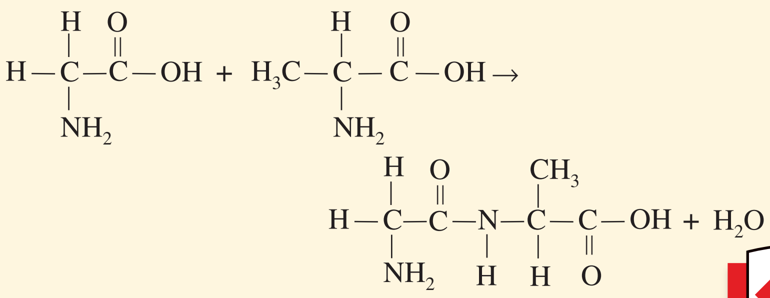
a. $CH_3CH_2CH_2NH_2Br$ and H_2
b. $CH_3CH_2CH_2NH_3$ and Br_2
c. $CH_3CH_2CH_2NH_2$ and HBr
d. $CH_3CH_2CH_3$ and NH_2Br

4. What type of compound does this molecule represent?



a. an amine **c.** an ester
b. an amide **d.** an ether

5. What kind of reaction is this?



a. substitution **c.** addition
b. condensation **d.** elimination

Interpreting Tables Use the table to answer the following questions.

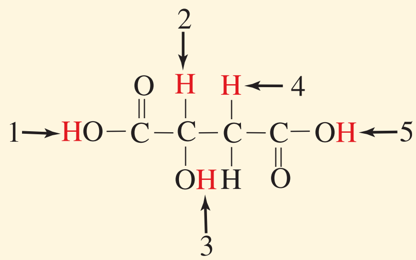
Acid Ionization Constants for Selected Carboxylic Acids

Common name	Formula	Hydrogen ionized	K_a
Succinic acid	$C_2H_4(COOH)_2$	1st	6.92×10^{-5}
		2nd	2.45×10^{-6}
Oxaloacetic acid	$C_2H_2O(COOH)_2$	1st	6.03×10^{-3}
		2nd	1.29×10^{-4}
Acrylic acid	$C_3H_4O_2$	1st	5.62×10^{-5}
Malic acid	$C_4H_6O_5$	1st	3.98×10^{-4}
		2nd	7.76×10^{-6}

6. Oxaloacetic acid has a higher K_a than succinic acid because it probably possesses _____ .

a. fewer carboxyl groups
b. a less polar structure
c. additional functional groups that make it more soluble in water
d. fewer hydrogen atoms that can transfer to the oxygen atom in H_2O

7. Which of the indicated hydrogen atoms will malic acid lose when it ionizes completely?



a. 1 and 5 **c.** 2, 3, and 4
b. 1, 3, and 5 **d.** 2 and 4

THE PRINCETON REVIEW **TEST-TAKING TIP**

Use As Much Time As You Can You will not get extra points for finishing early. Work slowly and carefully on any test and make sure you don't make careless errors because you are hurrying to finish.